SEWAGE WORKS JOURNAL

Vol. V SEPTEMBER, 1933 No. 5

Special Articles

Newark, N. Y., Plant—*Holmes*

Effect of Dilution on Bacteria in Polluted Water—*Hoskins and Butterfield—Heukelekian*

Sewage Sampling—*New England Committee*

[illegible]

[illegible]

[illegible] D.—*Eldridge*

Di[illegible] Below Thermophilic Range—*Heukelekian*

OFFICIAL PUBLICATION OF THE
[illegible]

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

OFFICERS

Chairman

C. A. EMERSON, JR., Fuller and McClintock, 170 Broadway, New York, N. Y.

Vice-Chairman

ABEL WOLMAN, Chief Engineer, Maryland State Department of Health, 16 W. Saratoga St., Baltimore, Md.

Secretary-Treasurer

H. E. MOSES, Assistant Chief Engineer, Pennsylvania State Department of Health, Harrisburg, Pa.

Business Manager

WM. W. BUFFUM, General Manager, The Chemical Foundation, 654 Madison Ave., New York, N. Y.

Editor

F. W. MOHLMAN, Chief Chemist, The Sanitary District of Chicago, 845 S. Wabash Ave., Chicago, Ill.

Board of Control

HENRY C. ADAMS, London, Eng.
H. G. BAITY, Chapel Hill, N. C.
FLOYD G. BROWNE, Marion, Ohio
WM. W. BUFFUM, New York City
C. H. BULLEN, Stillwater, Okla.
ANSELMO F. DAPPERT, Albany, N. Y.
H. J. DARCEY, Oklahoma City, Okla.
JOHN R. DOWNES, Bound Brook, N. J.
F. H. DRYDEN, Salisbury, Md.
V. M. EHLERS, Austin, Tex.
C. A. EMERSON, JR., New York City
LEWIS FINCH, Indianapolis, Ind.
L. M. FISHER, New York City
GLENN C. FOX, Marceline, Mo.
A. W. FUCHS, New York City
W. E. GALLIGAN, Ames, Iowa
JOHN H. GARNER, Wakefield, Eng.
A. D. HAMLYN, London, Eng.
JOHN HAWORTH, Sheffield, Eng.
CHAS. G. HYDE, Berkeley, Calif.
W. SCOTT JOHNSON, Jefferson City, Mo.
MAX LEVINE, Ames, Iowa
W. S. MAHLIE, Fort Worth, Tex.
C. D. MCGUIRE, Columbus, Ohio
H. E. MOSES, Harrisburg, Pa.
H. A. OLSEN, Pontiac, Mich.
W. J. ORCHARD, Newark, N. J.
EARLE B. PHELPS, New York City
WM. M. PIATT, Durham, N. C.
MISS JANE H. RIDER, Tucson, Ariz.
A. M. RAWN, Los Angeles, Calif.
WILLEM RUDOLFS, New Brunswick, N. J.
JAMES R. RUMSEY, Grand Rapids, Mich.
WARREN J. SCOTT, Hartford, Conn.
J. F. SKINNER, Rochester, N. Y.
RICHARD C. SMITH, Glen Ridge, N. J.
H. W. STREETER, Cincinnati, Ohio
DARIO TRAVAINI, Phoenix, Ariz.
L. F. WARRICK, Madison, Wis.
FREDERICK C. WILLIAMS, Pawtuckett, R. I.

ABEL WOLMAN, Baltimore, Md.

SEWAGE WORKS JOURNAL

REG. U. S. PAT. OFF.

A Bimonthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of sewage works.

Publication Office: 20th and Northampton Sts., Easton, Pa.

Editorial Office: 845 S. Wabash Ave., Chicago, Ill.

Subscription Price:

Members of Local Sewage Works Associations affiliated with the Federation, $1.00 per year.

Non-members: Total fee $3.00, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50 per year; other countries, $4.00 per year.

Foreign Subscriptions must be accompanied by International Money Order.

Single copies: United States, $1.00 each; Foreign, $1.25 each.

Manuscript may be sent to the Editor, F. W. Mohlman, 845 S. Wabash Ave., Chicago, Ill., for acceptance or rejection subject to the provisions of the Federation constitution.

Subscriptions, advertising copy and address changes should be sent to the Business Manager's Office at Easton, Pa., or at 654 Madison Ave., New York, N. Y.

No claims will be allowed for copies of Journals lost in the mails unless such claims are received within sixty (60) days of the date of issue and no claims will be allowed for issues lost as a result of insufficient notice of change of address. "Missing from files" cannot be accepted as the reason for honoring a claim.

Entered as second-class matter, October 2, 1928, at the post office at Easton, Pa., under the Act of March 3, 1879.

EFFICIENT operation of a sewage disposal plant is impossible unless the influent mains are proof against infiltration. Cast iron pipe should therefore be used for any new sanitary lines which will eventually be part of a disposal system.

Cast iron mains, if properly constructed, are proof against infiltration—joints are tight and remain so permanently. For this reason alone, sanitary engineers foresee a greatly increased use of cast iron pipe for sanitary mains. Longest life and lowest maintenance cost are additional advantages of cast iron pipe.

We shall be glad to supply further information upon request. Please address The Cast Iron Pipe Research Association, Thomas F. Wolfe, Research Engineer, 309 Peoples Gas Building, Chicago, Ill.

"Look for the Q-check."

CAST Q IRON

TRADEMARK REG.

TWO CAST IRON SANITARY LINES UNDER THE RAHWAY RIVER, AT RAHWAY, N. J.

CAST IRON PIPE

CHAIN BELT COMPANY

The Tow-Bro Removes More Sludge With Less Disturbance

The Tow-Bro Clarifier removes sludge directly without plowing or moving it around in the tank.

The inlet nozzles travel just above the tank bottom and remove the sludge the moment they come in contact with it. The radial headers, into which these nozzles empty, move 30 inches above the floor, so that there is almost no turbulence in the tank, either as the slow moving mechanism moves through the tank or after it has passed, as the nozzles do their collecting by hydrostatic pressure.

The Tow-Bro sweeps the entire tank bottom in a single revolution and the nozzles are graduated so that a uniform layer of sludge is removed.

The sludge flows along through the headers to the central outlet and then down into the sludge pipe line under the tank bottom. In practical sewage plant operation the Tow-Bro Clarifier offers these advantages:

1. A more concentrated sludge is obtained—hence there is less returned sludge to be pumped—leaving more capacity through the aeration and final settling tanks.
2. A clearer effluent is obtained—because the sludge is removed from the entire tank bottom with less disturbance so that a better settling condition obtains.
3. The sludge has less chance to become septic—because it is in the tank a shorter time.
4. The sludge may be drawn off at a faster rate—even with a light sludge blanket—without a diluting vortex action into the clarified supernatant liquor. This gives greater operating flexibility and greater settling tank capacity.

The Tow-Bro Clarifier is offered and recommended by the Chain Belt Company, exclusively, primarily for sludge removal from secondary settling tanks in activated sludge plants but also for final settling ("humus") tanks in trickling filter plants.

CHAIN BELT COMPANY, 1606 WEST BRUCE STREET, MILWAUKEE, WIS.

SANITATION EQUIPMENT

Sewage—Trade Wastes—Water Treatment

Established 1891—Branches or Representatives in all Principal Cities

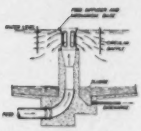
THE DORR SIFEED CLARIFIER

The latest in sedimentation practice

Sixteen 112 ft. dia. Dorr Sifeed Clarifiers at Cleveland's new Easterly plant. George B. Gascoigne was the consulting engineer.

The large installation of the new Dorr Sifeed Clarifiers, pictured above, brings to Cleveland's new Easterly plant the latest development in mechanically cleaned sedimentation tanks. Into the new Dorr Sifeed Clarifier have been engineered the final developments of a quarter of a century of sedimentation experience.

- **Central feed, hence heaviest particles settle directly over discharge hopper.**
- **Gentle subsurface diffusion, thus assuring quiescent radial flow without turbulence or plunging.**
- **A weir length more than three times the diameter, giving gradually decelerated flow reaching a minimum at point of overflow.**
- **Central or traction drive, whichever you prefer, with round tanks or square ones.**
- **Compact, attractive appearance, devoid of unsightly superstructures, motor housings, etc.**



SIFEED means centrally diffused, siphon feed; radially distributed flow; and peripherally collected overflow.

The net result of these new Dorr features is either a greater capacity per unit of tank size, or, conversely, a greater removal of suspended solids at former rates of flow.

DORRCO

It will pay you to investigate.

THE DORR COMPANY, Inc.

Engineers · 247 Park Ave., New York

Chicago Denver Los Angeles Toronto

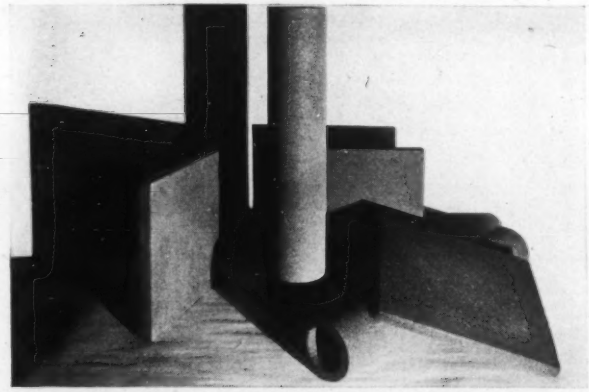
Affiliated with OLIVER UNITED FILTERS, INC.

CONSIDER THE PHYSICAL COMPOSITION OF

ALOXITE BRAND

REG. U. S. PAT. OFF.

DIFFUSER PLATES AND TUBES



EVERY cubic inch of every plate or tube is uniformly hard, homogeneous and uniformly porous.

Uniformity begins with the extremely accurate grading of the selected aluminum oxide grain—a scientific screening process that absolutely insures uniform diffusion.

The grain is bonded with special clays—plates and tubes are moulded to shape under high pressure and vitrified at high temperatures.

Each grain is thoroughly coated and its edges rounded off by the bond, thus presenting a smooth, easy air passage of minimum frictional resistance.

You can add to these properties of hardness—homogeneity and uniform porosity, the properties of high tensile strength, high porosity and durability.

All combining in the ideal diffuser mediums for aeration of sewage to secure required special properties of exact permeability, uniform diffusion and low pressure loss.

Send for the Special Engineering Bulletin

THE CARBORUNDUM COMPANY • *Niagara Falls, N. Y.*

REG. U. S. PAT. OFF.

CANADIAN CARBORUNDUM CO., LTD., NIAGARA FALLS, ONT.

(CARBORUNDUM AND ALOXITE ARE REGISTERED TRADE MARKS OF THE CARBORUNDUM COMPANY)

Sewage Pumps Have Been Improved by "Chicago"...

Exclusive Non-Clog Features

Fig. 1774 "Chicago" Horizontal Non-Clog Pump

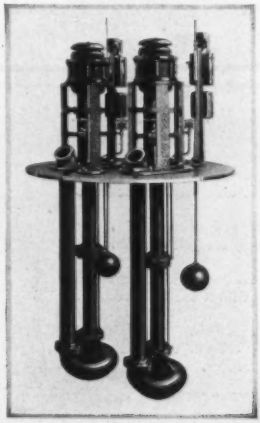


Fig. 2087 Duplex "Chicago" Vertical Enclosed-Shaft Non-Clog Sewage Pumps

Improved "Chicago" Sewage Pumps are giving truly non-clogging trouble-free service. They give the same efficient service year after year, and never drop off in capacity.

NRA MEMBER U.S. WE DO OUR PART

CHICAGO PUMP COMPANY

SEWAGE-CONDENSATION-CIRCULATING
BILGE-FIRE-HOUSE-VACUUM

2300 Wolfram St. CHICAGO

Sewage Works Journal

Published by

Federation of Sewage Works Associations

Easton, Pa.

Copyright, 1933, by Federation of Sewage Works Associations

Vol. V **September, 1933** **No. 5**

Page

Sewage Research:

Digestion of Solids Between the Thermophilic and Non-Thermophilic Range. By H. Heukelekian 757
Some Observed Effects of Dilution on the Bacterial Changes in Polluted Water. By J. K. Hoskins and C. T. Butterfield 763
Effect of Dilution of Sewage on Bacterial Numbers. By H. Heukelekian. 774
More About the Biochemical Oxygen Demand Determination. By E. F. Eldridge 788

Plant Operation:

Activated Sludge Treatment Replaces Imhoff Tanks and Sprinkling Filters at Newark, N. Y. By Glenn D. Holmes 793
Sewage Aeration by Diffused Air. By Frank C. Roe 813
Report of Committee on Sewage Sampling, New England Sewage Works Association. By C. C. Carson, S. DeM. Gage, L. H. Geer, M. C. Whipple, and Roy S. Lanphear 826
Comments of Rudolfs' and Miles' Articles on "Heat Losses from Sludge Digestion Tanks." By T. R. Haseltine 844
The Pumping of Sewage and Sludge. By Charles E. Greene 858
Sewage Treatment at Jamestown, N. Y. By L. A. Bergman 864

Editorial:

The Fate of Bacteria in Polluted Waters 870

Employment Service 872

Proceedings of Local Associations:

Pennsylvania Sewage Works Association Seventh Annual Conference 873

Reviews and Abstracts (H. W. Streeter):

The Purification of Beet Sugar Wastes, Introductory Note. By H. W. Streeter 876
The Purification of Waste Waters from Beet Sugar Factories. By E. H. Richards and D. W. Cutler 877
Studies on the Treatment of Beet Sugar Factory Wastes. Report No. 1. By E. T. Eldridge and F. R. Theroux 881

Purification of Beet Sugar Wastes. By MAX LEVINE 884
Design and Operation of the Esholt Works of the Bradford Corporation. By H. WONTNER-SMITH 885
Coatbridge Sewage Purification and Sludge Disposal Works 888
Purification of Trade Wastes (Halifax, England) 890
Human Sewage Effluents Harmless to Cattle 891
Dewatering of Sludge. By A DRAINAGE ENGINEER 892
Sewage Treatment at Burnley 892
Death of Fish from Cyanides in Coke-Oven Effluents. By C. H. S. TUPHOLME 893
Heating Top Sludge, II. By HENRY W. TAYLOR 894
Pre-Aeration of Sewage by Air Diffusion. By FRANK C. ROE 894
Operation of a Small Sewage Treatment Plant. By FLOYD G. BROWNE 895
Some Causes and Effects of Stream Pollution. By J. K. HOSKINS 896
The Removal of Cyanide from Plating Room Wastes. By E. F. ELDRIDGE. 897

JOIN YOUR STATE OR
LOCAL SEWAGE WORKS
ASSOCIATION

AFFILIATE WITH THE NATIONAL FEDERATION
OF SEWAGE WORKS ASSOCIATIONS

Members of the Federation receive

THE SEWAGE WORKS JOURNAL

for one dollar per year

Non-members' subscription in U. S.
is three dollars per year; Canada,
three dollars and fifty cents; foreign,
four dollars.

Send Subscriptions to

WM. W. BUFFUM, Business Manager
654 Madison Ave.
New York, N. Y.

Sewage Research

Digestion of Solids Between the Thermophilic and Non-Thermophilic Range*

By H. Heukelekian

Associate, Dept. Sewage Research, New Brunswick, N. J.

Investigations have shown that digestion can be accomplished within two different temperature ranges—thermophilic and non-thermophilic. The optimum temperature for the non-thermophilic is 28° C. and for the thermophilic range 50° to 55° C. However, nothing definite is known for temperature ranges between these two optima. There are three possible explanations for this intermediate zone: (1) As we increase the temperature from the non-thermophilic optimum and decrease from the thermophilic optimum the digestion will proceed more slowly. This presupposes two definite processes with their exclusive flora, and an intermediate zone which is not optimum for either. (2) As the temperature is increased above 28° C. the digestion time becomes progressively shorter and there is no break in the curve until the thermophilic range is reached. This possibility presupposes that digestion is a direct function of temperature and therefore the flora adjust themselves to the various temperature conditions without sharp lines of demarcation. (3) As the temperature is increased above 28° C. to the thermophilic digestion range, digestion time is neither increased nor decreased.

Keefer and Kratz[3] recently reported results which tend to uphold the third assumption. They compared the digestion of solids at 28° and 37° and arrived at the conclusion that digestion at 37° C. was slightly more rapid than at 28° C.

Previous work from this laboratory[4] seemed to indicate that as the temperature was increased above 28° C. the digestion time was lengthened, confirming the first assumption.

The work reported here was started in 1931 with the hope of obtaining more definite knowledge regarding the progress of digestion between the two optimum ranges of temperature.

Method

The experiments were conducted with separate batches of sludge. Sludge from a 20° C. separate sludge-digestion tank was obtained and

* *Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Sewage Research.*

mixed with fresh solids. Separate portions of this mixture were incubated at 28°, 33°, 37° and 42° C. After the digestion was completed these sludges were used as seed for digesting equal amounts of fresh solids, re-incubated at their original temperatures. In other words sludge produced at 28° C. was used as seed for digesting more fresh solids at the same temperature. This process was repeated four times in succession. Daily gas measurements were made. The volumes of fresh solids and ripe sludge used in each experiment were such that exactly 10 grams of dry volatile

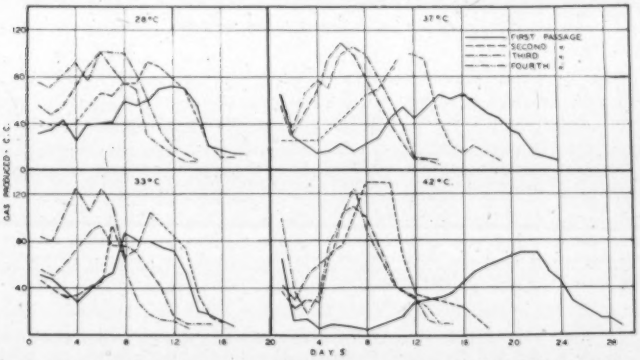


FIG. 1.—Daily Gas Production at Various Temperatures with Successive Re-Use of the Sludge (Cc. per Gram Volatile Matter Added).

matter in fresh solids and 5 grams of dry volatile matter in ripe sludge were taken.

Results

The results of the daily gas production during the four passages as described above for the different temperatures of digestion are presented in graphic form in Figures 1 and 2. It appears that even at 28° C. the last two passages gasified more rapidly than the first two. In the first two passages the gas peak was attained very gradually after 10 to 11 days, while in the last two, the maximum was reached in 6 days. At 33° C. a similar relationship was observed. At 37° C. the divergence between the successive passages became greater. The first passage exhibited a prolonged lag and a low peak. In the second passage the lag was decreased considerably, the peak was more pronounced and was attained in 11 days. The third and fourth passages were similar in their rates of gas production. There was no lag period and the peak was attained in 6 days. At 42° C.

the period of lag for the first passage was even more pronounced than at 37° C. and the recovery was complete with the second passage.

In order to determine the time necessary to produce 90 per cent of the total gas the following procedure was followed: When the daily gas production dropped to 10 cc. per gram of volatile matter the digestion was

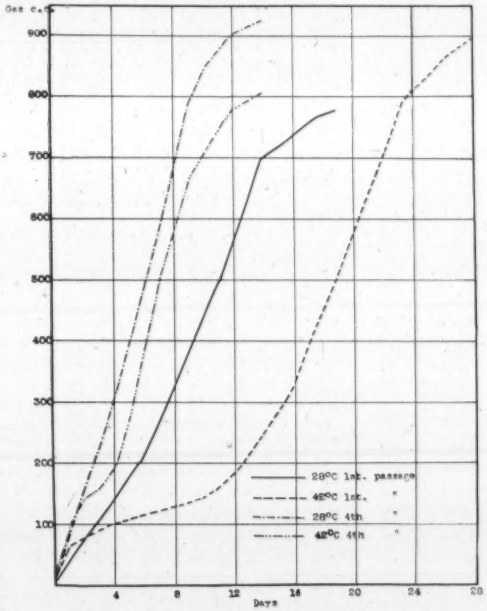


FIG. 2.—Cumulative Gas Production at 28° C. and 42° C. with the First and Fourth Re-Use of the Sludge (Cc. per Gram Volatile Matter Added).

considered complete. The total gas production up to that point was noted and the day when 90 per cent of it was produced was computed. The results are given in Table I. There was a maximum variation of total gas yield from 720 to 990 cc. per gram of volatile matter in the different series. However, the average yields for the four passages give a higher yield for the 42° C. digestion than for any of the other temperatures.

The reduction in the time as a result of the four passages was 4 days for 28° C., 5 days for 33° C., 11 days for 37° C. and 14 days for 42° C.

Discussion

From the above results it is apparent that a single passage would be entirely misleading when the digestion rates are compared at different temperatures with sludges produced at 20° C. If the experimentation had stopped at this stage we would draw the conclusion that digestion at 37° and 42° C. is not as favorable as at 28° or 33° C. This would explain such a statement previously made from this laboratory, as those results were based on a single passage. It is only natural to expect that until the flora established in the 20° C. sludge adapts itself to the radically different temperature conditions employed a lag would follow. This lag, as well as the 90 per cent gas production time, is of increasing order as the temperature increases from the base line at 20° C. When the sludge produced at 37° and 42° C. (with their flora partially established by previous acclimatization) is used again, a substantial reduction in the lag and

TABLE I

EFFECT OF ACCLIMATIZATION TO TEMPERATURE ON GAS PRODUCTION AND DIGESTION TIME

	28° C.		33° C.		37° C.		42° C.	
	Total Gas, Cc.	90% Gas, Days	Total Gas, Cc.	90% Gas, Days	Total Gas, Cc.	90% Gas, Days	Total Gas, Cc.	90% Gas, Days
1st	780	14	800	13	950	21	990	25
2nd	930	13	900	13	870	14	790	13
3rd	720	9	760	10	730	9	800	11
4th	925	10	855	8	840	10	880	11
Avg.	840		830		847		860	

time for 90 per cent gasification is accomplished. However, even the second passage is not sufficient for a complete establishment of the flora adapted to 37° and 42° C. as a third passage accomplishes a further reduction in time. Henceforth the sludge can be properly called appropriate for digestion at these respective temperatures. It is to be seen that a similar change and subsequent reduction of time has taken place at 28° and 33° C. but to a smaller extent.

The second significant point is that after this adaptation has taken place the results achieved are not materially better at one temperature than at another. In other words the different flora established at these temperatures bring about the digestion in essentially the same time. Perhaps 33° C. is somewhat a better optimum for low temperature digestion than 28° C. Our results, however, do not show that digestion at 37° C. is slightly better than at 28° C. as Keefer and Kratz have shown with Baltimore sludge. They do not state the temperature of the original ripe sludge nor whether this sludge was previously acclimatized to the respective temperatures. It is to be noted also that their digestion time, as measured by gas

production, is somewhat longer than reported here for similar temperatures.

The results show that as the temperature is increased above 28° C. and until the thermophilic range is reached, digestion time is neither increased nor decreased. However, this does not mean that the digestion is accomplished by the same flora at 42° C. as at 28° C.

Previous work[1] with batch process in the thermophilic range showed the best digestion time to be 12 days. With the continuous process laboratory experiments a two-day digestion time seemed to be sufficient. Carefully controlled semi-plant scale experiments, on the basis of daily additions, should be made to determine the actual capacities necessary at these various temperatures. This phase of the problem is now being studied in this laboratory.

Just what the adaptation of sludges to various temperatures involves from the standpoint of bacterial flora is not known at the present time. It appears that organisms capable of digesting sludge, for example, at 37° C., are present in a 20° C. sludge but require a sufficiently long period for adequate increase in their numbers in order to carry on the digestion at the higher temperature. The higher the temperature is raised above the temperature of the seed sludge the longer will be the period necessary for the development of the new flora. Now if we reverse the process, as sometimes inevitably happens, and the sludge cools below the prevailing digestion temperature, it has been observed that digestion and gasification are retarded. In other words, we are dealing with replacement of the high temperature organisms with the low temperature organisms, and until the low temperature organisms predominate, the rate of digestion is retarded. However, when it is merely a question of storage of high temperature sludge without further additions, as it has been shown previously[2], this can be accomplished just as effectively at 20° C. as at 50° C. without affecting the subsequent digestion when additions of raw material are resumed. It may therefore be expected that with temperatures of 42° and 37° C. the effect of storage will be similar.

Summary

It has been shown that a sludge produced at 20° C. requires a period of adaptation and acclimatization to give the most efficient digestion at higher temperatures. The larger the difference between the temperature at which a sludge was produced and the temperature at which it is used for digestion, the greater will be the initial retardation and the greater will be the benefits derived from subsequent re-use of the sludge. Adaptation seems to be complete with the third passage. These results make it imperative not to draw conclusions from batch digestion at different temperatures without a preliminary acclimatization of the sludge. The ultimate

digestion time from the batch process does not vary materially in the range of temperature between 28° and 42° C.

References

[1] H. Heukelekian, "Further Studies on Thermophilic Digestion of Sewage Solids," THIS JOURNAL, **2**, 219–27 (1930).

[2] H. Heukelekian, "Certain Environmental Conditions Affecting the Value of Thermophilic Seed Sludge," *Ibid.*, **4**, 986–92 (1932).

[3] C. E. Keefer and H. Kratz, "Digesting Sludge at 37° C.," *Loc. cit.*, **5**, 262–6 (1933).

[4] W. Rudolfs, "Effect of Temperature on Sewage Sludge Digestion," *Ind. Eng. Chem.*, **19**, 241 (1927).

Some Observed Effects of Dilution on the Bacterial Changes in Polluted Water

BY J. K. HOSKINS AND C. T. BUTTERFIELD

Sanitary Engineer and Principal Bacteriologist, U. S. Public Health Service, Stream Pollution Investigations, Cincinnati, Ohio

Increasing amounts of domestic and industrial wastes, from our urban and industrial centers, have focused attention on the problem of stream pollution because the most common method of disposal of urban sewage is by dilution; a procedure which employs nature's processes for the reduction of organic materials and pathogenic bacteria. In many cases these agencies of dilution and natural purification are not able to bear the excessive burden of pollution contributed, and the urge for artificial remedial measures becomes acute.

It is therefore of two-fold value to investigate the interplay of some of the factors active in the self-purification of polluted water and the conditions which affect their efficient functioning. Although the reactions are complex and are undoubtedly affected by numerous factors such as temperature, time, concentration of food material, oxygen supply and others, it appears that oxidation of a great variety of substances is brought about by the action of numerous families of bacteria which have the power of reducing complex chemical compounds to more stable and simple ones in the presence of oxygen.

Recently reported experimental studies[1] indicate quite definitely that this oxidation process occurs only during the stage of active multiplication of bacterial cells and that if for any reason this increase in the number of cells is retarded or stimulated, the oxidation process is correspondingly affected. It must be borne in mind that it is not the mere number of cells but the rate at which the cells are actually developing that is the governing factor. In addition it has been proved, in the article referred to, that in any suitable medium where bacteria only are present, the bacterial population tends to reach a limiting density quite promptly, after which very little additional multiplication takes place. Under such conditions the bacteria apparently exist in a resting state, relatively little food material is used and, coincidentally, further oxidation of organic material practically ceases.

Nature, to prevent such a stalemate and to provide for continuous multiplication of bacterial cells, has provided methods for the stimulation of their growth. One of these is by the continuous reduction of bacterial numbers below their limiting density by bacteria-eating plankton. Under such conditions there is then established what may be termed a biological balance in which the bacteria, on the one hand, multiply continuously at the expense of the available food material, and the plankton, on the other hand,

keep the bacterial numbers constantly reduced below their upper limiting population. Eventually, as the food material decreases, bacterial growth is retarded, the bacteria-eating plankton also diminish due to an increasing scarcity of their food and there results a water with greatly reduced levels of organic pollution, bacteria and bacteria-eating plankton—in other words, a "self-purified" or "naturally purified" water.

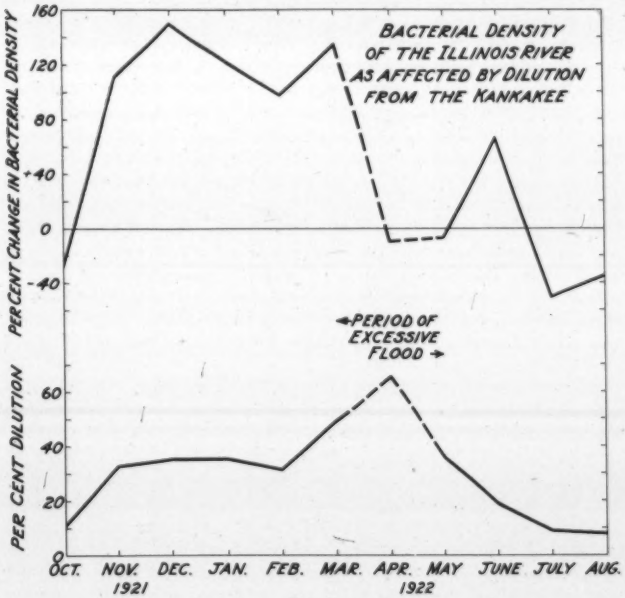


FIG. 1.

It would be expected that, if this biological balance were disturbed—that is, if the orderly procedure of bacterial multiplication with consequent oxidation of pollutional material and subsequent bacterial destruction by plankton were interrupted—some interference with the orderly rate of purification would result. It is therefore of considerable interest to examine some of the effects of such a disturbance of the biological balance as would be created by dilution as observed both in natural streams and under experimental conditions.

In the course of our studies of the pollution and natural purification of

various rivers, frequent opportunities have occurred to observe the effects of dilution in natural streams. This dilution may be of one of two types: (1) the case where sewage is discharged into a less polluted watercourse or (2) where a highly polluted stream is diluted by the inflow of a comparatively pure tributary.

In the case of streams receiving large quantities of sewage, it has been noted frequently that the maximum bacterial density of the complete mixture is not observed immediately below the sewer outlets but at varying distances below, the distance being greatest at the higher river stages, that is at times when the dilution is greatest. These observations are discussed at length in *U. S. Public Health Bulletin* **143,** pages 239 and 276.[2]

An example of a polluted stream being diluted by a tributary is that of the Illinois River, which carries an excessive burden of pollution from the Chicago Drainage Canal and which has an important tributary, the Kankakee, a relatively unpolluted stream. The percentage change in the bacterial content, based on monthly averages as observed in the Illinois, in passing the mouth of the Kankakee and after correction for the bacterial content of the diluting stream, is given in the following summary and illustrated in Figure 1:

Month	Per Cent Dilution of Illinois by Kankakee	Percentage Change in Pollution Density from Upper to Lower Station as Measured by: Gelatin Count	Agar Count	*Coli-Aerogenes*	5-Day Oxygen Demand
1921					
October	11.3	− 23.2	− 21.3	.....	0
November	33.0	+ 65.7	+109	+126	+50.7
December	35.6	+156	+241	+ 83.5	+60.0
1922					
January	35.6	+118	+110	+ 39.6	+74.0
February	31.6	+ 19	+ 85.6	+ 22.1	+39.1
March	49.5	+157	+118	+242	+83.5
April	65.5	− 19.8	− 16.9	+ 30.2	− 4.3
May	36.0	− 45.2	+ 6.9	− 7.5	0
June	19.0	+ 59.2	+ 65.8	+ 53.7	+36.4
July	9.0	− 48.9	− 51.4	− 26.9	−27.3
August	7.8	− 32.3	− 35.8	+ 60.2	0

With regard to the plate counts, it is observed that in all months when the dilution was over 15 per cent, appreciable increases in bacteria occurred except in April and May, 1922, a period of excessive flood stages and unusual conditions of flow throughout the river system. The *Coli-aerogenes* group enumerations show even more consistent increases. It is possible that scouring velocities induced by the greater volumes of water contributed by the Kankakee may have had the effect of stirring up bottom deposits accumulated during lower water stages and that such disturbance would result in an increase in the bacterial content at the lower station.

It seems improbable, however, that this could always be the case; moreover during the excessive flood stages of April and May when such scour must have been at a maximum, it was not sufficient to effect an increase in bacteria between the upper and lower stations.

A similar, though less marked effect was noted in the Illinois River as a result of the contribution of other less polluted tributaries, such as the Fox and the Des Plaines Rivers. These streams never produced a dilution of over 20 per cent of the highly polluted river flow, yet, during four months of the year, increases of bacteria were observed in the Illinois in passing from above to below the junction with the Fox when the dilution ranged from 8 to 17 per cent. Similar increases in bacterial numbers occurred in the sewage from the Main Drainage Canal as a result of the dilution effected by the inflow of the Des Plaines River during three months when the flow ranged from 10 to 16 per cent of that of the highly polluted canal water.

A converse condition, simulating the introduction of sewage into a stream, is that of the Scioto River, a branch of the Ohio River. This smaller, but more highly polluted tributary discharges into a larger but less polluted river. During a period of ten months, over which observations are available, the average monthly flow of the Scioto never exceeded 15 per cent of that of the Ohio and only during one month exceeded 10 per cent. Yet, during this interval, increases in bacterial numbers as measured by the gelatin plate count in the Ohio below the junction were observed during seven months and by the agar and *Coli-aerogenes* group counts during four months.

In the study of conditions in the upper Mississippi River,[3] an increase in quantity units of bacteria was noted in the main stream below the inflow of an important tributary, the Chippewa River. This bacterial increase was observed during four months out of the six for which data were available. During these four months the flow of the Chippewa was from 75 to 100 per cent of that of the main river.

Crohurst, in his report of the resurvey of the Ohio River,[4] page 95, states in his discussion of the bacterial data that, "The bacteriological results in the vicinity of the Great Miami River suggest that under certain conditions the regular decrease in bacteria below the point of maximum concentration may be temporarily interrupted, the dilution by the tributary apparently affecting the biological balance of the stream to such an extent that a temporary increase in organisms is indicated in the section between Stations 492 and 503."

This rather extensive accumulation of evidence from natural sources would seem to show beyond doubt that under certain conditions dilution of a polluted stream, or pollution of a fairly pure stream, brings about an increase in bacterial numbers at lower sampling stations. It is therefore

of further interest now to examine the effects of dilution under experimental conditions where the variables and sources of error can be more carefully controlled.

Experimental

Each of a series of 15 samples of water collected over a period of three months from Mill Creek, Cincinnati (a relatively small stream heavily polluted with domestic and industrial sewage), was thoroughly agitated and then divided into seven portions. Three of these portions were

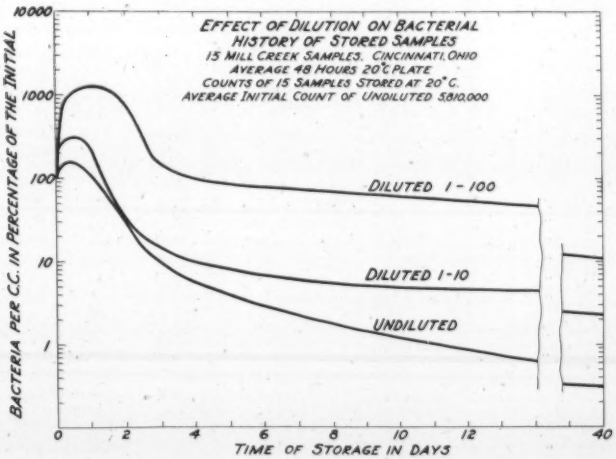


FIG. 2.

stored, undiluted, in glass bottles, at temperatures of 10°, 20° and 37° C., respectively. Two other portions were diluted 1 to 10 with sterilized Cincinnati tap water and stored one at 20° and the other at 37° C. In a similar manner the two remaining portions were diluted 1 to 100 with sterile tap water and incubated at 20° and 37° C. Examinations were made immediately, and after successive periods of time, from each of the stored portions to determine the numbers of bacteria growing on gelatin incubated at 20° C., for 48 hours and on agar incubated at 37° C. for 24 hours, as well as for the *Coli-aerogenes* group content. The average results from these 15 series of observations are summarized in Table I and illustrated in Figure 2.

An inspection of these data indicates that the increase in bacterial density

TABLE I

EFFECT OF DILUTION ON BACTERIAL COUNT OF STORED SAMPLES FROM MILL CREEK
Results in Terms of Percentage of Initial Count

A. Gelatin Plates Incubated 48 Hr. at 20° C.

Time of Storage	Undiluted Initial Count, 5,810,000 per Cc. Stored at:			Diluted 1–10 Initial Count, 594,000 per Cc. Stored at:		Diluted 1–100 Initial Count, 60,000 per Cc. Stored at:	
	10° C.	20° C.	37° C.	20° C.	37° C.	20° C.	37° C.
0 Hrs.	100	100	100	100	100	100	100
4 "	138	136	142	264	314	355	896
8 "	119	125	131	246	258	923	1174
20 "	132	128	44.7	286	40.9	1197	956
24 "	114	100	11.1	236	167	1245	685
48 "	131	30.4	3.55	31.2	7.06	815	106
72 "	104	9.60	1.07	14.4	5.59	148	67.7
6 Days	29.4	2.88	0.39	6.86	1.93	79.8	30.7
13 "	2.11	0.73	0.104	4.56	0.57	48.1	2.07
40+ "	0.30	0.32	0.017	2.27	0.35	10.6	0.99

B. Agar Plates Incubated 24 Hr. at 37° C.

	Initial Count 12,440,000 per Cc.			Initial Count 1,270,000 per Cc.		Initial Count 129,000 per Cc.	
0 Hrs.	100	100	100	100	100	100	100
4 "	132	137	153	298	323	393	805
8 "	130	166	157	288	305	1020	1232
20 "	203	178	43	346	26.2	1490	1157
24 "	166	147	11	274	11.5	1280	825
48 "	107	17.1	2.18	18.8	3.83	652	60.4
72 "	120	7.82	0.72	10.6	3.27	114	48.0
6 Days	30.2	2.00	0.44	5.44	1.66	49.0	21.4
13 "	0.85	0.68	0.086	3.43	0.31	27.7	1.54
40+ "	0.15	0.25	0.017	1.95	0.12	7.24	0.49

C. *Coli-Aerogenes*

	Initial Count 256,000 per Cc.			Initial Count 25,000 per Cc.		Initial Count 1840 per Cc.	
0 Hrs.	100	100	100	100	100	100	100
4 "	105	302	168	124	161	109	228
8 "	107	329	110	175	155	136	314
20 "	29.5	100	32.5	158	21.9	145	95.3
24 "	31.9	50.5	19.9	52.0	9.75	210	91.4
48 "	55.3	16.9	9.33	10.7	2.74	135	27.5
72 "	22.4	14.2	2.02	3.28	1.58	21.4	13.0
6 Days	7.44	2.36	0.29	5.15	0.24	20.4	2.65
13 "	0.81	1.69	0.04	1.29	0.44	13.5	0.58
40 "	0.20	0.12	0.01	0.54	0.01	5.3	0.01

during the first few hours of storage occurred regularly as has always been observed in stored samples.[6] However, it appears that the bacteria in the diluted portions multiplied more rapidly and to a greater extent than those in the undiluted portions stored under the same conditions. Moreover the highest rate of increase invariably occurred in the highest dilution of the sample. Thus in the portions stored at 20° C., the percentage

increase at the end of the 8-hour storage period, as measured by the 20° C. count, was: in the undiluted portion 125, in the 1–10 dilution 246 and in the 1–100 dilution 923. Similar differences are to be observed in the 20° plate counts of portions stored at 37° C., as well as in the 37° plate counts of samples stored at 20° and at 37° C.

When the results obtained at the 24-hour storage period are compared, an additional variation is observed. The bacteria in the undiluted portions have decreased to the initial content; in the 1–10 dilution they are decreasing but have not yet been reduced to the initial content; while in the 1–100 dilution the maximum has just been reached. This difference in the rate and extent of decrease in the different portions prevailed at subsequent storage periods. The effect was always most marked in the 1–100 dilution.

It is of interest also to examine the actual maximum density of bacteria

TABLE II

AVERAGES OF MAXIMUM BACTERIAL COUNTS FROM 13 MILL CREEK SAMPLES IN PORTIONS UNDILUTED, DILUTED 1–10, AND DILUTED 1–100, AND STORED AT 20° AND 37° C.

Temperature of Storage, ° C.	Plates Incubated at ° C.	Undiluted Dilution Ratio = 100 Average at Maximum Bacterial Density		Diluted, 1–10 Dilution Ratio = 10 Average at Maximum Bacterial Density		Diluted, 1–100 Dilution Ratio = 1 Average at Maximum Bacterial Density	
		Bacteria per Cc.	Per Cent of Undiluted	Bacteria per Cc.	Per Cent of Undiluted	Bacteria per Cc.	Per Cent of Undiluted
20	20	7,960,000	100	1,854,000	23.3	958,700	12.05
20	37	24,070,000	100	4,330,000	18.0	1,908,000	7.91
37	20	8,146,000	100	1,702,000	20.9	735,000	9.02
37	37	21,670,000	100	4,042,000	18.6	1,680,000	7.75
Average			100		20.2		9.18

reached in the several portions of these samples. The average maximum numbers of bacteria, both in the diluted and undiluted portions, for each temperature of storage and of counts, are presented in Table II.

By computing the relative increase in bacteria in the diluted over that in the undiluted portions, a measure of the effect of dilution may be obtained. Thus in the group of samples stored at 20° C., the average maximum count of the undiluted portions was 7,960,000 per cc. and of the portions diluted 1–10 was 1,854,000. If the same relative increase had occurred in the diluted as in the undiluted portions, the anticipated density in the former would be 796,000 bacteria per cc., instead of 1,854,000 or 233 per cent of the anticipated number. These observed increases are reasonably consistent for each dilution regardless of the temperature of storage or the method of enumeration of the bacteria. Judged from the diminution in food supply due to dilution, the average maximum counts in the undiluted portion and those diluted 1–10 and 1–100 would be expected to be in the order of 100, 10 and 1, respectively. As a matter of fact these values were 100, 20.2 and 9.18. In other words, the maximum count in the

1–10 dilution was 2 times and in the 1–100 dilution was 9 times its anticipated magnitude. Under the controlled conditions of these tests, this difference must be attributed to the effects of dilution.

Further studies on the effect of dilution on the bacteria in stored samples of water from the Illinois River gave similar results. This stream is grossly polluted at its source by the sewage of the Chicago metropolitan area.

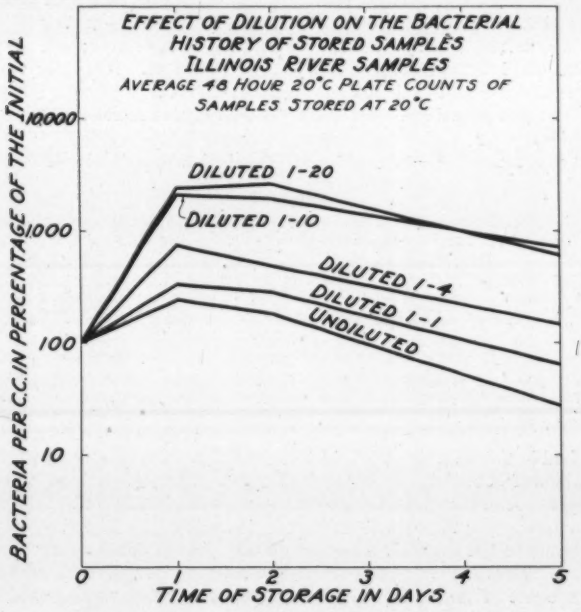


FIG. 3.

However, bacterial purification is very rapid, so that in the course of 120 miles the bacterial density as measured by gelatin counts has, during the summer months, decreased from over 3,000,000 to about 5000 per cc. Samples of this polluted water were collected at a series of six sampling stations. These samples were divided into separate portions in each instance, and diluted to various degrees with sterile distilled water. The several portions were then stored in the dark at 20° C., and examined bacteriologically at definite time periods. The average results of these

observations are presented in Table III and a representative series is illustrated in Figure 3.

TABLE III

EFFECT OF VARIOUS DEGREES OF DILUTION ON RATE OF BACTERIAL INCREASE IN STORED SAMPLES OF ILLINOIS RIVER WATER

Results in Terms of Percentage of Initial Counts

A. Gelatin Plates Incubated 48 Hr. at 20° C.

Time of Storage, Days	Undiluted	Diluted to 50 Per Cent	Diluted to 25 Per Cent	Diluted to 10 Per Cent	Diluted to 5 Per Cent
	Station 288.1	Illinois River		Average of 3 Samples	
0	100	100	100	100	100
1	32.6	37.3	36.8	98.2	165
2	11.8	10.9	16.0	28.8	103
5	1.71	1.33	2.68	4.06	14.8
	Station 240	Illinois River		One Sample	
0	100	100	100	100	100
1	42.6	84.5	62.0	485	855
2	24.2	52.3	59.0	510	1240
5	9.65	15.3	17.0	42.1	155
	Station 227	Illinois River		Average of 4 Samples	
0	100	100	100	100	100
1	246	339	770	2,140	2440
2	180	283	500	1,950	2660
5	27.5	65.5	149	711	602
	Station 196	Illinois River		Average of 2 Samples	
0	100	100	100	100	100
1	177	186	207	384	559
2	145	190	217	407	553
5	16.9	26.2	65.2	151	478
	Station 179	Illinois River		Average of 2 Samples	
0	100	100	100	100*	
1	309	1,860	3,800	12,800*	
2	275	2,410	5,840	20,100*	
5	180	1,240	3,000	11,300*	
	Station 166	Illinois River		One Sample	
0	100	100	100	100*	
1	2360	29,000	34,100	972*	
2	5750	80,500	204,000	67,900*	
5	1830	9,380	18,300	23,400*	

B. Agar Plates Incubated 24 Hr. at 37° C.

Time of Storage, Days	Undiluted	Diluted to 50 Per Cent	Diluted to 25 Per Cent	Diluted to 10 Per Cent	Diluted to 5 Per Cent
	Station 288	Illinois River			
0	100	100	100	100	100
1	41.2	34.1	35.4	102	213
2	13.0	11.6	15.5	33.9	106
5	1.75	1.54	3.21	4.52	17.1

TABLE III (*Continued*)

	Station 240	Illinois River			
0	100	100	100	100	100
1	33.1	38.1	104	890	2120
2	15.1	27.5	69.5	970	2180
5	10.8	9.74	83.8	180	436
	Station 227	Illinois River			
0	100	100	100	100	100
1	280	420	772	2,250	1570
2	181	285	654	3,100	2910
5	63.5	120	204	915	2420
	Station 196	Illinois River			
0	100	100	100	100	100
1	190	260	251	268	340
2	73.5	255	50.7	512	922
5	12.4	15.8	34.6	114	271
	Station 179	Illinois River			
0	100	100	100	100[a]	
1	213	1,230	3,920	10,500[a]	
2	405	2,000	5,430	14,200[a]	
5	158	1,270	2,960	10,700[a]	
	Station 166	Illinois River			
0	100	100	100	100[a]	
1	4590	111,300	85,200	2,940[a]	
2	8830	172,000	405,000	68,300[a]	
5	6100	37,400	33,700	46,000[a]	

[a] Diluted to $12^1/_2$ per cent.

It will be noted that no increase in numbers of bacteria was observed in the undiluted samples of the two uppermost stations where the initial densities were greatest, and moreover that increases occurred only in the higher dilutions of these samples. However, as the distance from the source of sewage pollution increased, the tendency of stored samples to increase in bacterial density became more pronounced. The same tendency to increased bacterial density in successively higher dilutions of samples from the same source is also quite marked and consistent in this series. Thus under experimental conditions it again appears that dilution of a polluted water brings about some profound change in the stored sample that permits a fundamental readjustment of bacterial life.

As to the reason for this apparent increase in bacterial numbers following dilution, certain explanations may be offered. A biological balance prevails in a polluted water under natural conditions. In this biological balance the bacteria are maintained below their limiting number by bacteria-destroying agencies, particularly the protozoa. When dilution

occurs, the biological balance is disturbed and the bacterial density is reduced below the concentration required for the protozoa that are present. Such conditions at once favor a temporarily uninterrupted multiplication of bacterial cells and the bacteria would have an opportunity to increase in numbers extensively, before the biological balance could be reëstablished. Time for such multiplication is also provided because the generation time of the bacteria is very much less than that of the protozoa. It would follow also that the bacterial increase would be relatively greater and extend over a longer period of time in proportion as the percentage of dilution is increased.

While these studies clearly demonstrate the influence of dilution on the bacterial content of polluted water, observations on a greater number of streams under varying conditions of dilution, bacterial concentration and temperature are needed to establish more definitely the general trend of this dilution effect. If, from such extended observations, it is found that a temporary reversal of the course of the natural bacterial decrease generally results when waters of marked variations in bacterial concentration are mixed together, some of the puzzling results obtained at times in the study of polluted waters will be explained.

References

[1] C. T. Butterfield, W. C. Purdy and E. J. Theriault, "The Influence of the Plankton on the Biochemical Oxidation of Organic Matter," *Public Health Reports*, **46**, 393–426 (February 20, 1931). Reprint No. 1451.

[2] Wade H. Frost, J. K. Hoskins, R. E. Tarbett and H. W. Streeter, "A Study of the Pollution and Natural Purification of the Ohio River. II. Report on Surveys and Laboratory Studies," *Public Health Bulletin*, No. **143** (July, 1924).

[3] H. R. Crohurst, "A Study of the Pollution and Natural Purification of the Upper Mississippi River," *Public Health Bulletin*, No. **203** (Dec., 1932).

[4] H. R. Crohurst, "A Study of the Pollution and Natural Purification of the Ohio River. IV. A Resurvey of the Ohio River between Cincinnati, Ohio, and Louisville, Kentucky, Including a Discussion of the Effects of Canalization and Changes in Sanitary Conditions Since 1914–1916," *Public Health Bulletin*, No. **204**.

[5] C. T. Butterfield, "Observations on Changes in Numbers of Bacteria in Polluted Water," THIS JOURNAL, **5**, 593 (July, 1933).

Effect of Dilution of Sewage on Bacterial Numbers*

BY H. HEUKELEKIAN

Associate, Department Sewage Research, N. J. Agr. Expt. Sta., New Brunswick, N. J.

The literature of stream pollution is replete with references to factors which influence the death rates of bacteria, such as temperature, protozoa, aeration, bacteriophage, sunlight, salts, pH, etc. The initial concentration of sewage or polluted water is an additional factor which may affect the rate of disappearance of bacteria. Streeter[1] makes the observation that the addition of dilution water from tributaries less polluted than the main stream frequently results in an increase rather than a decrease in the bacterial content of the main stream.

Dilution is an important factor in stream self-purification. Such factors as food supply, presence or absence of dissolved oxygen, number and variety of protozoa and rate of bacterial decrease are dependent largely on the degree of dilution of sewage in streams. It has seemed worth while to us to study some of these factors by bacterial examination of various samples of sewage, diluted and undiluted, stored at 20° C. in the laboratory.

The results from such a method of study are not directly applicable to stream conditions since it is impossible to reproduce conditions of natural reaeration, and since aerobic conditions in our various dilutions could not be kept constant with incubation. However, the laboratory tests are of value in explanation of the possible reasons for some of the phenomena observed in the bacterial study of polluted streams.

Method

Screened sewage was diluted with phosphate buffer water. The phosphate buffer water was used to prevent the plasmolytic effect of distilled water in higher dilutions. It consisted of 47.5 mg. of KH_2PO_4 per liter, adjusted to pH 7.2 with NaOH. The degree of dilution varied from 0 to 99.5 per cent. The bottles were filled completely and tightly stoppered. Incubation was at 20° C. At each interval an unopened bottle was taken for analysis in order to avoid the effect of shaking and possible aeration. The bacterial analysis consisted of (1) the enumeration of colonies on nutrient broth agar (20° C. for 4 days) and (2) counts on Noble's ferrocyanide citrate agar for the enumeration of *B. coli* and *B. aerogenes*. For the purpose of this study no differentiation between the two groups was attempted.

* *Journal Series Paper, N. J. Agr. Expt. Sta., New Brunswick, N. J., Dept. Sewage Research.*

Results

The results of the total counts for the different dilutions of sewage are given in Table I and Figures 1 and 2. The numbers in the sewage decreased materially up to the second day, on the 4th and 6th days of incubation a definite increase was noted, followed by a decrease thereafter.

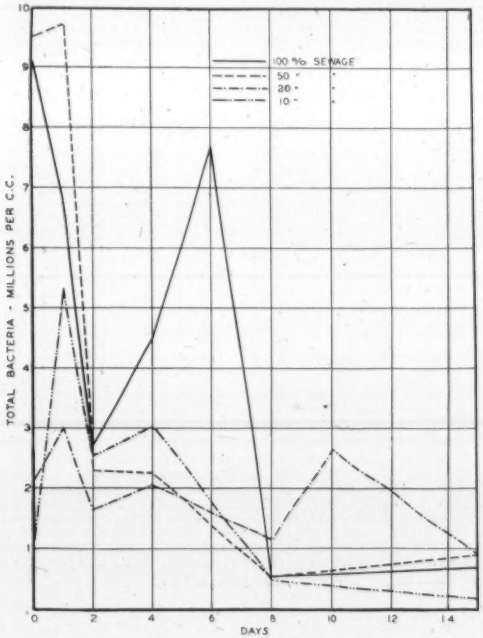


FIG. 1.—Effect of Dilution of Sewage on Total Bacteria (Agar Plate Counts, 4 Days at 20° C.).

The sewage diluted 50 per cent did not show a decrease the first day but from then on a rapid and permanent decrease took place. All of the remaining dilutions showed a definite initial increase on the first or second day of incubation. The magnitude of this initial increase was greater with increasing dilution, down to 5 per cent. With still higher dilutions of 2.5, 1 and 0.5 per cent, the magnitude of the initial increase was less.

The bacterial count at the end of 15 days of incubation was not materially affected by the initial dilution of the sewage nor the initial bacterial population and was less than 1,000,000 per cc. for the three lowest dilutions and less than 400,000 per cc. for the higher dilutions. The 5 per cent dilution, which gave the highest initial increase, gave the lowest bacterial population after 15 days and 0.5 per cent dilution gave the most uniform population throughout the incubation period.

The *B. coli* counts as obtained by the direct ferrocyanide citrate method

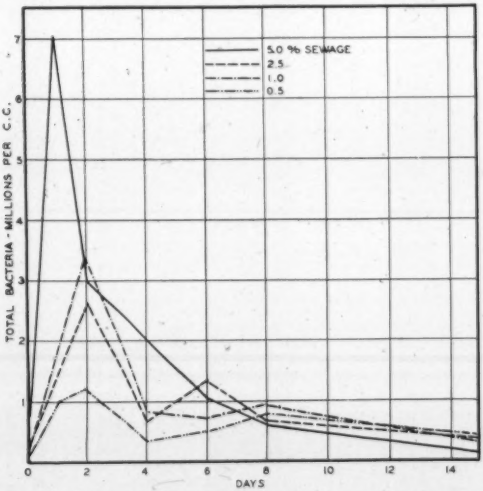


FIG. 2.—Effect of Dilution of Sewage on Total Bacteria (Agar Plate Counts, 4 Days at 20° C.).

are given in Table II, Figures 3 and 4. With 100 per cent and 50 per cent sewage there was a slight increase the first day followed by a rapid decrease to a low level the following day. With 20 and 10 per cent the increase on the first day was greater but was again followed by a decrease on the second day. The 5 per cent dilution gave a very large increase of *B. coli* the first day, similar to total plate counts. With 2.5, 1.0 and 0.5 per cent dilutions counts were not obtained the first day. All dilutions, however, showed a very rapid decline after the first day and a low level was reached thereafter, irrespective of the initial dilution or the count.

In the next experiment observations on the initial rise of bacterial

population were made at shorter intervals during the first 24-hour period. The sewage used was from one of the New Brunswick, N. J., sewer outfalls and was strictly fresh. The dilutions were made with phosphate

TABLE I

EFFECT OF DILUTION OF SEWAGE ON THE NUMBERS OF TOTAL BACTERIA[a]

(Thousands per Cc.)

Days	Dilution, Per Cent 100	50	20	10	5	2.5	1.0	0.5
0	9100	9500	2110	1117	480	330	143	54
1	6800	9700	3030	5350	7000	1000[b]	1000[b]	1000
2	2800	2300	1650	2570	3120	2600	3400	1200
4	4450	2250	2050	3050	...	670	780	370
6	7700	1450	1140	1920	1090	1360	750	500
8	620	550	2700	450	600	700	950	780
15	680	900	985	145	170	380	330	400

[a] Nutrient agar plates incubated 4 days at 20° C.

[b] From overcrowded plates due to insufficient dilution.

TABLE II

EFFECT OF DILUTION OF SEWAGE ON THE NUMBERS OF *B. coli* AND *B. aerogenes*[a]

(Per Cc.)

Days	Dilution, Per Cent 100	50	20	10	5	2.5	1.0	0.5
0	140,000	91,000	29,000	7,500	3,500	1100	3200	130
1	160,000	100,000	54,000	50,000	28,000	...[b]	...[b]	...[b]
2	17,000	15,000	5,100	5,600	700	1400	700	340
4	2,800	1,000	6,000	2,000	1,200	600	...	120
6	700	1,900	1,300	2,200	3,700	180	1000	10
8	2,300	170	850	150	2,100	110	30	50

[a] Noble's ferrocyanide citrate agar.

[b] No counts could be obtained on account of insufficient dilution.

TABLE III

EFFECT OF DILUTION ON NUMBERS OF TOTAL BACTERIA (THOUSANDS PER CC.)

Hours	Dilution, Per Cent 100	50	20	10	5	2.5	1.0
0	2200	1,390	670	340	315	247	363
6	3485	1,300	1230	750	520	540	385
12	4900	5,600	7800	4300	2180	950	910
24	9200	11,300	7700	7300	7500	3550	3500
48	3650	4,800	4150	960	540	1320	1000+
72	1500	2,600	690	340	175	470	1220
Max. Increase Over Original Numbers	318%	710%	1050%	2050%	2280%	1340%	870%

buffer in the same way as before. The results for total plate counts are given in Table III and Figures 5 and 6. As noticed previously, the bacterial population increased initially. This initial increase was progressive for all the dilutions during the first 24-hour period. Some of the dilutions

did not indicate an increase during the first 6-hour period, but thereafter there was an increase in all dilutions up to 24 hours and thereafter a decrease to a level on the third day. Unlike the previous series the undiluted sewage in this case showed a sharp initial increase. The variation was probably due to a difference in freshness of the sewage, as will be brought out more fully in a later paper. The first studies were made with Plainfield sewage, which is strong and septic in character. The sewage was used on the day after its collection. In the second series the sewage was obtained from New Brunswick, and was medium and fresh in character. The dilutions and initial observations were made on the day the sewage was obtained.

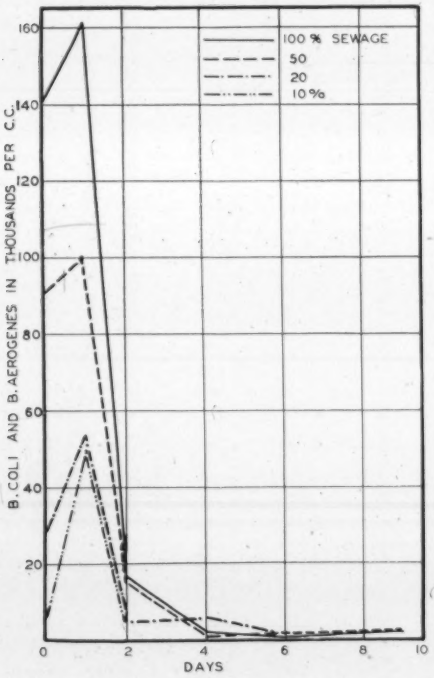


FIG. 3.—Effect of Dilution of Sewage on *B. coli* and *B. aerogenes* (Noble's Ferrocyanide Citrate Agar).

The results for *B. coli* and *B. aerogenes* obtained by ferrocyanide citrate agar are shown in Table IV and Figures 5 and 6. They show a gradual increase for 24 hours and then a sharp decrease. The rate of decrease for these organisms was somewhat greater than for the total counts.

Discussion

Perhaps the most interesting result was the increase in the total as well as *B. coli* counts with dilution. Neither the 100 nor the 50 per cent sewage indicated material initial increases in the first series. Starting with

20 per cent sewage down to 0.5 per cent the initial increase in both the total counts and *B. coli* increased with the dilution. Table V gives the maximum percentage increase over the original numbers and the day on which this increase occurred. There is a definite progressive increase, with increasing dilution, in the percentage of bacteria and *B. coli* over original numbers.

In the second series, in which a fresh sewage was used, increases in the number of bacteria took place even with the undiluted sewage. The maximum increase over the original numbers of total bacteria and *B. coli* is given in Tables III and IV. The per cent increase in total bacteria was greater with the higher dilutions, up to 5 per cent. The per cent increase in the *B. coli* group, however, showed no definite relation with the dilution. It should be noted that the increase in this series was decidedly higher than in the previous series. The increase, as will be shown in a later publication, is dependent on the age of sewage. Whatever the magnitude, however, the phenomenon of initial bacterial increase was consistent throughout this study.

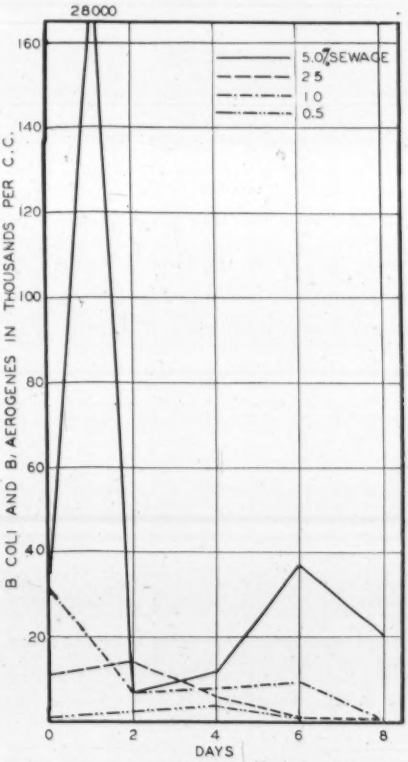


FIG. 4.—Effect of Dilution of Sewage on *B. coli* and *B. aerogenes* (Noble's Ferrocyanide Citrate Agar).

Bacterial Increase and Oxygen Tension.—The dissolved oxygen was

reduced to zero in all dilutions down to 5 per cent. Initial oxygen was zero in the undiluted sewage, and no increase in numbers took place in this sample as may be seen from Table V. In the 50 per cent mixture the initial D. O. probably disappeared during the first 24-hour period; the

TABLE IV

EFFECT OF DILUTION ON NUMBERS OF *B. coli* AND *B. aerogenes* (FERROCYANIDE CITRATE AGAR)

Hours	Dilution, Per Cent 100	50	20	10	5	2.5	1
0	37,500	25,000	15,500	12,260	1,400	1,100	420
6	.....	11,000	42,000	8,000	4,100	280	910
12	700,000	750,000	400,000	35,000	62,000	21,000	2500
24	870,000	950,000	440,000	140,000	97,000	29,000	8000
48	44,000	8,400	7,100	5,300	5,300	1,200	620
72	38,000	.....	8,500	7,100	600	2,300	950
Max. Increase over Original Numbers	220%	370%	2,740%	1,060%	6,830%	2,530%	1960%

increase in bacterial numbers was small. There was no D. O. with either 20 or 10 per cent mixtures at the end of the 24-hour period but bacterial increases took place. From 5.0 to 0.5 per cent mixtures the D. O. was present in increasing quantities at the end of the first 24-hour period and the bacterial increases were progressively greater. Thus there appears

TABLE V

THE RATE OF INCREASE OF TOTAL BACTERIA AND *B. coli* AS INFLUENCED BY DILUTION

	Dilution, Per Cent 100	50	20	10	5	7.5	1.0	0.5
Total Counts, Max. Per Cent Increase over Original	0	+ 2.1	+43.5	+380	+1360	+690	+2280	+2120
B. coli, Max. Per Cent Increase over Original	+14	+10	+86	+570	+700	...	...	...
Day on Which Max. Increase Occurred	1	1	1	1	1	2	2	2
D. O. Present Initially, P. p. m.	0	3.5	6.0	7.4	7.8	7.7	7.4	7.3
D. O. When the Increase Occurred, P. p. m.	0	0	0	0	1.9	4.8	7.0	7.3

to be a correlation between the D. O. content of the mixtures and the bacterial increases, but it is impossible to say whether the increases were made possible by the presence of dissolved oxygen or whether other consequences of dilution were responsible for the increase.

The relation between the D. O. content of the various dilution and the changes in bacterial population for the second series of experiments are

shown graphically in Figures 5 and 6. Essentially the same conclusion can be drawn with the closer periods of observation as noted above, namely, that other factors than dissolved oxygen content are primarily responsible

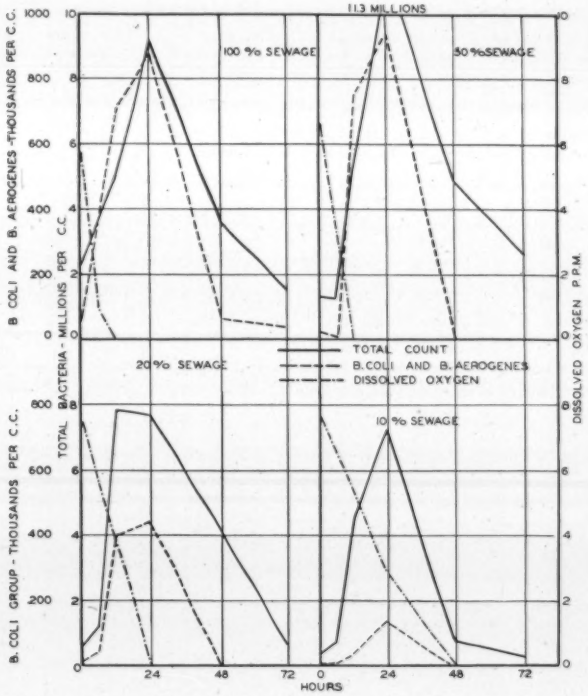


FIG. 5.—Effect of Dilution of Sewage on Total Plate Counts and *B. coli* Group.

for changes in bacterial population. The increase in bacterial population took place while D. O. was decreasing and also after it had totally disappeared.

Bacterial Increase and Fauna.—It would not be expected that protozoa would influence the initial increase in bacterial numbers, although they may play an important rôle in reduction of bacterial population after

maximum numbers have been reached. An examination of four dilutions of sewage was made for bacteria and protozoa after 24 hours' incubation. The results are presented below. *Trepomonas*, which is exclusively an anaerobic protozoan, was present in the 100 per cent sewage after 24 hours. *Colpoda* and *Bodo* were present in 20 and 5 per cent mixtures and no protozoa could be found in the 1 per cent dilution.

In view of the paucity of types and numbers of protozoa, it is hardly likely that this played an important rôle in bacterial changes during the first 24 hours. It is possible, however, that significant and interesting changes may occur in the types and numbers of protozoa after the maximum bacterial population has been established;

Per Cent of Sewage in Sample	Bacterial Increase, Per Cent	Protozoa per Cc.
100	−24.6	20−24 *Trepemonas*, no other protoza
20	282	16 *Colpoda* and 32 *Bodo*
5	545	16 *Bodo*
1	406	No protozoa

Effect of Dilution Water and Buffer Salts.—The next factor that suggests itself as an explanation for the increase in bacterial numbers is the influence of potassium phosphate added in the dilution water. Several series of dilutions were run using distilled water as diluting medium:

TABLE VI

EFFECT OF DILUTING SEWAGE WITH DISTILLED WATER ON THE NUMBERS OF *B. coli* (LACTOSE BROTH)

	Per Cent Reduction or Increase Days			
Dilution, Per Cent	1	2	4	6
100	79	94.5	99.5	99.9
50	+163	+58	95.5	99.0
25	+80	+80	82.0	90
12.5	62	+280	62.0	0
8	+58	+370	+58	52.5
4	21.1	90	73.5	94.5
2	0	44.5	99.0	91
1	40	+100	88	40
0.5	99	+16	74	95

The results are given in Table VI. The *B. coli* were determined by the lactose broth method in this series. The striking feature of the results is the irregularities and the fluctuations in bacterial reduction. In part these are to be attributed to the inaccuracy of the determination by the lactose broth method.

It is apparent that the undiluted sewage does not give any increase. There are increases of *B. coli* numbers from 50 to 8 per cent dilutions but

with higher dilutions the increase is less noticeable. The failure of the bacteria to increase with higher dilutions when using distilled water may be explained because of plasmolysis of the cells. In other respects these results bear out in general the observations made above.

In using phosphate buffer water we have overcome the objections in using distilled water but it may conceivably have caused the multiplication of the bacteria. However, before the increase in bacteria can be ascribed to the phosphate we have to assume that phosphates in sewage are a limiting factor. The bacterial requirement of phosphate is small and it is probable that sewage would contain an ample supply of phosphates to prevent a deficiency. It is also difficult to see why, for in-

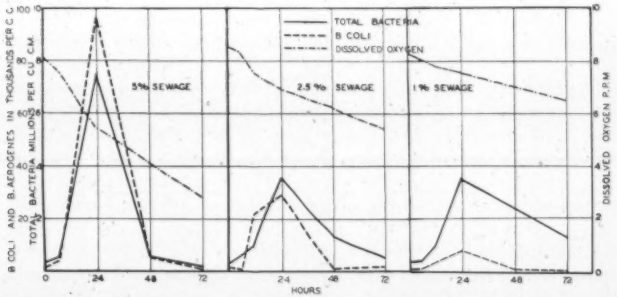


FIG. 6.—Effect of Dilution of Sewage on Total Plate Counts and *B. coli* Group.

stance, an increase of 5 per cent in the dilution water (from 90 to 95 per cent dilution water) could possibly cause the observed bacterial increase, in these dilutions, due to the very slightly greater amount of phosphate added in this way.

The effect of potassium ion as a dispersing agent on colloids and bac-

TABLE VII

	Potassium Phosphate				Calcium Phosphate		
	100%	20%	5%	1%	20%	5%	1%
% Maximum Increase in Total Bacteria	−24.6	282	545	406	46	1740	320
% Maximum Increase of *B. coli*[a]	−59.5	83	33	220	100	1120	450

[a] By ferrocyanide citrate agar method.

terial aggregation should also be considered. For that reason a comparison was made of potassium phosphate and calcium phosphate dilution waters. The calcium phosphate buffer solution was made from $CaH_2PO_4 \cdot 2H_2O$ (47.5 p. p. m.) and the pH was adjusted with $Ca(OH)_2$ to 7.2.

If calcium ion acted as a coagulating ion and potassium as a dispersing ion we should not obtain as high increases with calcium ion as with potassium, but as can be seen from Table VII in many instances the increases in various dilutions is higher with calcium than with potassium phosphate buffer solution. We therefore cannot ascribe the increase to a specific effect of the ions.

Bacterial Increase and pH Values.—Cohen,[2] states that the zone of optimum pH for *B. coli* is wide and centers around neutrality. With the buffered dilution waters the pH value of the water initially was 7.2 and did not drop below 6.7. Therefore we cannot attribute the differences to pH values *per se*.

There have been several similar observations in regard to initial increases of *B. coli*. In an earlier publication we have called attention to the initial increase of *B. coli* in the digestion of fresh solids.[3] The studies of the U. S. Public Health Service on the Ohio[4] and Illinois[5] rivers have brought out the interesting observation that the numbers of bacteria in a stream show an initial increase below the point of maximum sewage pollution. More recently Calvert[6] in the report of the British Water Pollution Research Board has reported similar increases of bacteria and *B. coli* after 5 days, when autoclaved sewage was seeded with a small amount of sewage. In another part of the report it is stated that when autoclaved sewage was seeded with a small amount of *B. coli* there was no increase during the first 5-day period of incubation. The number of *B. coli* in the small amount of seed was 1,754,700 per cc. and in the larger amount of seed 218,-331,300 per cc. The numbers in the smaller amount are higher than the largest number of *B. coli* present in our sewages. It is also interesting to observe that with a small seeding of *Ps. fluorescens* (3340 per cc.) an increase of bacterial numbers took place, while with large seeding of the same organism there was no such increase. It would be interesting to know whether *B. coli*, when added in as small numbers as *Ps. fluorescens*, would register an initial increase.

Butterfield and Purdy[7] in their interesting paper have shown that when *B. aerogenes*, *B. coli* and *P. proteus* are inoculated into dilute dextrose peptone in the presence of oxygen supply, the counts increase to a limiting population level at the end of 24 to 48 hours and maintain this level for a long period of time. When bacteria and plankton were grown together the bacterial numbers increased in the same way as when the bacteria were present alone. After the first two days, however, the bacterial numbers decreased rapidly, the reduction being accompanied by a plankton increase. The results obtained by Butterfield and Purdy with mixed flora and fauna inoculated into synthetic peptone-dextrose water parallel ours with sewage and its normal flora and fauna.

Thus there seems to be considerable corroborative evidence that there

is an initial multiplication of bacteria. The explanation for this phenomenon, however, is not definite. An adequate explanation should include the increasing rate of multiplication for higher dilutions of sewage.

In diluting sewage as we have done the food supply and the number of bacteria in the diluted material are reduced according to the dilution. It is therefore to be expected that the bacterial increase might be less in higher dilutions. Since such is not the case the food supply as such cannot be the determining factor. If, however, there is a definite maximum population level that can be established under a definite set of conditions, covering a range of dilutions, then the fewer the initial number of bacteria the higher the rate of multiplication will be in order to establish such a level. However, as indicated above, in diminishing the numbers of bacteria by dilution we have also reduced the food supply to the same extent. Therefore, if this were the true explanation we must assume that the food

TABLE VIII

RATIO OF TOTAL COUNTS TO *B. coli*

(From Tables I and II)

Days	Dilution, Per Cent 100	50	20	10	5	2.5	1.0	0.5
0	65	105	73	149	137	300	45	410
1	42.5	97	56	107	250	...	....	.....
2	165	152	320	460	4450	1850	4,850	3,500
4	1,600	2250	330	1520	...	1120	....	3,000
6	11,000	1450	880	870	295	7550	750	50,000
8	250	290	1160	3000	286	6350	31,700	15,600

supply even in highest dilution was more than the minimal requirement for the establishment of such a level. The maximum population level attained was, however, lower with higher dilutions. (See Figures 1–4.) Thus, though food supply was diminishing, the lowering of the initial bacterial numbers increased the rate of multiplication, but growth did not progress sufficiently to establish the same population level in all dilutions because of the limitation of food supply.

We should also consider the effect of dilution on the accumulation of bacterial waste products. After the maximum population level is established the subsequent reduction takes place quite rapidly. A low level of total counts is established in 3 to 4 days and in *B. coli* in 2 days. The explanation for the stage of decreasing numbers may be due to the (1) protozoa feeding on bacteria, as Butterfield and Purdy have pointed out, (2) the exhaustion of food supply, or (3) accumulation of waste products. Probably a combination of all these factors is responsible for the decrease.

A study of the results indicate that the *B. coli* disappear relatively more rapidly than the total bacteria as counted on agar. In Table VIII are given the ratios of total counts to *B. coli* in the various dilutions after

incubation for different periods. It is apparent that the ratios increase invariably with the period of incubation, indicating a relatively greater rate of disappearance of *B. coli* than of the general flora. During the first day the ratios are the same as initially, indicating no relative change in numbers. But the ratios increase rapidly thereafter, indicating that *B. coli* are either crowded out or replaced by bacteria probably of non-intestinal origin.

Streeter[1] adduces evidence in favor of multiplication or an increase due to subdivision of particles, from the higher numbers of bacteria recovered in a stream receiving sewage from known contributing population compared with the numbers known to exist in feces and sewage. A second source of evidence of such multiplication is brought forward by the fact that an increase in numbers was noted after initial or subsequent dilution from an unpolluted tributary. Our conclusions derived from controlled laboratory experiments bear out fully these observations. We are, however, inclined to believe that this phenomenon is an actual multiplication of bacteria rather than a mere disintegration of aggregates or clumps in sewage.

Summary

Changes in bacterial numbers, as measured by total count and Noble's ferrocyanide citrate agar for the enumeration of *B. coli* and *B. aerogenes*, were studied in samples of sewage diluted to various degrees with phosphate buffer solution and incubated at 20° C. An initial increase in the numbers of total bacteria and *B. coli* was observed in the first 24 hours of incubation. After the initial period of increase the numbers of both groups of organisms diminished rapidly and reached a low level in 3 to 4 days of incubation. There seemed to be no correlation between the initial dissolved oxygen content and the increase in bacterial numbers. Likewise there seemed to be no correlation between the bacterial counts and the numbers and types of protozoa. Tests indicated that neither the phosphate nor the potassium ions were the causes of this increase. It is suggested that according to Butterfield and Purdy's suggestion a maximum population level exists for a given set of conditions and, as the numbers of bacteria are reduced below that level, multiplication is induced. In sewage diluted to various degrees the food supply is also reduced, so that the resulting multiplication does not reach the same level as with lower dilutions, although the rate of increase is higher.

References

[1] H. W. Streeter, "The Effect of Sewage Discharge on Streams," THIS JOURNAL, **3**, 713–23 (1931).

[2] B. Cohen, "Disinfection Studies. The Effects of Temperature and Hydrogen Ion Concentration Upon the Viability of *Bact. coli* and *Bact. typhosum* in Water," *Jr. Bact.*, **7**, 183 (1922).

[3] H. Heukelekian, "The Fate of *B. coli* and *B. aerogenes* in Sewage Purification," *Jr. Bact.*, **14**, 55–67 (1927).

[4] H. W. Frost and H. W. Streeter, "A Study of the Pollution and Natural Purification of the Ohio River. Section 6, Bacteriological Studies," *Pub. Health Bull.* **143** (1924).

[5] J. K. Hoskins, C. C. Ruchhoft and L. Williams, "Study of the Pollution and Natural Purification of the Illinois River," *Pub. Health Bull.* **171** (1927).

[6] H. T. Calvert, Report of the British Water Pollution Research Board, **1932.**

[7] C. T. Butterfield and W. C. Purdy, "Experimental Studies of Natural Purification in Polluted Waters. IV. The Influence of the Plankton on the Biochemical Oxygen Demand of Organic Matter," *Pub. Health Repts.*, **46**, 393–426 (1931).

More About the Biochemical Oxygen Demand Determination

BY E. F. ELDRIDGE

Engineering Experiment Station, Michigan State College, East Lansing, Michigan

Perhaps the best topic for discussion at sewage works conferences and among sewage works operators is the biochemical oxygen demand determination. No other subject will cause a better argument than B. O. D. Why? Because this determination is apparently subject to more variations and discrepancies due to, as yet, unknown causes than any other test used in the sewage works laboratory.

The following quotation was taken from an editorial in the May, 1933, issue of THIS JOURNAL. "The apparently simple technique of the determination, as ordinarily made, leads to a feeling of dependability that is by no means justified when complicating factors arise due to the use of chemicals in sewage treatment. When, by certain types of treatment, the normal flora and fauna in a sample are disturbed, changed or eliminated, the use of the B. O. D. method can often lead to illogical results that puzzle even those who have studied the method for years."

The author has long been of the opinion that the number and type of bacteria and other microscopic organisms present in a B. O. D. dilution will govern, to a considerable extent, the utilization of oxygen in the sample. That is, given the same quantity of organic material the results will vary with the number of bacteria initially present when the sample is set away for incubation. Since this is one of the factors which might lead to the "illogical results" as mentioned in the above quotation, the following data may be of interest to those who are studying this problem.

Experimental

In making the B. O. D. determination on industrial wastes or on sewage which has been chemically treated, it is common practice to seed the dilutions for incubation with a small quantity of sewage. The seeding used, the quantity applied and the method of application have not been standardized and will depend upon the available material and the wishes of the laboratory worker.

In these experiments, in order to standardize the food supply on which the B. O. D. determination was made, certain sugars were used. Solutions containing one gram per liter of lactose, dextrose, sucrose, levulose and maltose were made as accurately as possible from purified laboratory sugars. These solutions were used for making up the B. O. D. dilutions.

The sewage for seeding was taken from the effluent of the Imhoff tank at East Lansing. This sewage was allowed to settle and the upper por-

tion of the liquid was then removed and used to seed the incubations.

Four series of experiments were made in which all conditions were the same except the quality of the seeding which would, of course, vary with the sewage being treated at the Imhoff tank. The seeding for the samples in any one series was the same.

The following procedure was used in making up the dilutions. Incubation bottles were checked for capacity and those selected which did not vary over ±2 cc. from 250 cc. Standard diluting water, distilled water containing 300 p. p. m. sodium bicarbonate, was used. The bottles were filled half full of diluting water, the measured quantities of sugar solution and sewage added and then completely filled. Water seals were fitted and the samples incubated at 20° C.

Series I.—The sewage used for seeding in this series was quite weak due to rainy weather. Three bottles received 1, 2 and 3 cc., respectively, of the seeding sewage in diluting water. Three more contained 10 cc. each of lactose and 1, 2 and 3 cc., respectively, of sewage. Dilutions of levulose, sucrose and dextrose were made up in a similar manner. The samples were incubated for 3 days.

Table I shows the results obtained.

TABLE I

3-DAY B. O. D. OF SEEDED SUGAR SOLUTIONS

Seeding, Cc.	Parts per Million B. O. D. Lactose	Levulose	Dextrose	Sucrose
1	60	45	48	48
2	145	80	95	110
3	182	155	160	150

The B. O. D. results were calculated from the difference between the D. O. after incubation of each dilution containing the sugar and the D. O. of the dilution containing the same quantity of sewage. Thus, the D. O. of a dilution containing 10 cc. of lactose and 1 cc. of sewage was subtracted from the D. O. of the dilution containing 1 cc. of sewage only. The B. O. D. was then calculated on the basis of the 0.1 per cent sugar solution. This method eliminated from the calculation the B. O. D. of the sewage, which was automatically taken care of in the procedure.

The results show that, in this case, with this particular sewage, the B. O. D. increased practically in proportion to the quantity of sewage used for seeding.

Series II.—In this series the work was extended to include a larger volume of the seeding sewage, which was still very dilute. The same procedure was used as before except that the 5-day B. O. D. was determined. Table II and Chart 1 show the result obtained.

These results are very similar to those obtained in Series I and show the general tendency to increase more or less in proportion to the quantity of seeding sewage used. In this series it was necessary to vary the quantity of sugar solution used in order to take in the wide range in B. O. D.

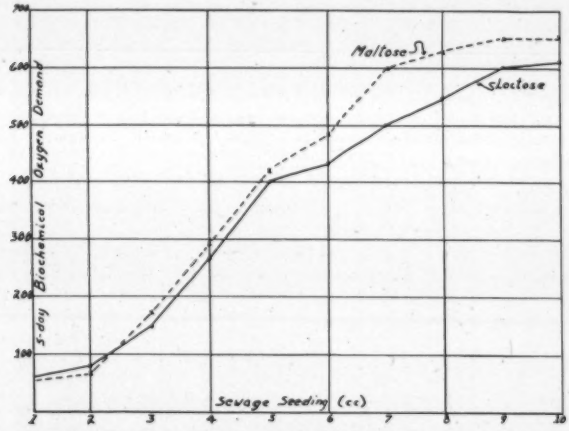


CHART I.—The Effect of Seeding on the B. O. D. of Lactose and Maltose Solutions.

TABLE II

5-DAY B.O.D. OF SEEDED SUGAR SOLUTIONS

(0.1 Per Cent Lactose and Maltose)

Sewage Seeding, Cc.	Sugar Solution, Cc.	B.O.D. Parts per Million Lactose	Maltose
1	10	60	55
2	10	110	95
3	5	150	170
4	5	270	290
5	2.5	400	420
6	2.5	450	480
7	2	500	550
8	2	545	630
9	1	600	650
10	1	600	650

From these data it appears that there might be an optimum quantity of seeding. This is indicated by a calculation of the theoretical amount of

oxygen required by the 0.1 per cent lactose solution, which is approximately 900 p. p. m. According to Phelps' formula the 5-day B. O. D. of this solution should be about 600 p. p. m. or 67 per cent of the total. This checks very well with the value obtained with the 9 and 10 cc. of seeding.

Series III.—In this series lactose only was used and sets of samples were incubated for 2, 4, 7, 10 and 20 days. Chart 2 shows the results of this series. From these curves it is apparent that there was a considerable lag in the rate of oxidation with the smaller quantities of seeding mixture and that the final B. O. D. (20-day) in each case was about the same and very near the theoretical.

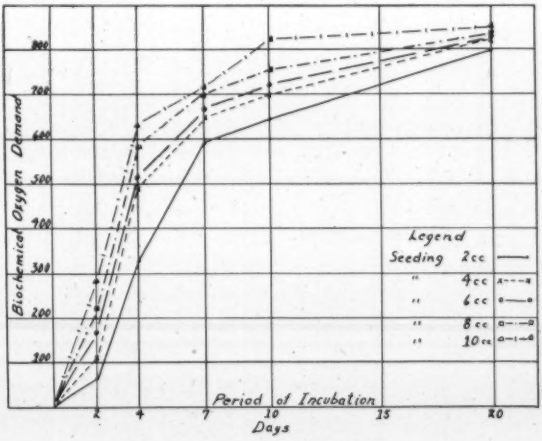


CHART II.—The Effect of Seeding on the B. O. D. of Lactose Using Various Periods of Incubation.

Series IV.—Series IV was made at a time when the sewage plant effluent used for seeding was much stronger than that previously used, therefore more organisms were added in the same volume. Lactose again was used and sets representing 2, 4, 7 and 9 day B. O. D.'s were run. The results (Chart 3) again show the lag in the earlier part of the oxidation with the lower quantities of seeding. Since the seeding was stronger, the extent of this lag was not as great as in the previous series. After 7 days of incubation with 3 cc. of this particular seeding, the results obtained were very constant. The 9-day incubations checked with all the quantities of seeding used.

Discussion

These results show that in making up B. O. D. dilutions of a sterile material, the quantity of seeding added greatly affects the values obtained. There appears to be an optimum quantity of seeding above which correct results are possible. The variation is undoubtedly due to a lag in the development of the organisms in the cases where the initial numbers are low. The B. O. D., at least up to 7 days' incubation, may vary to such an

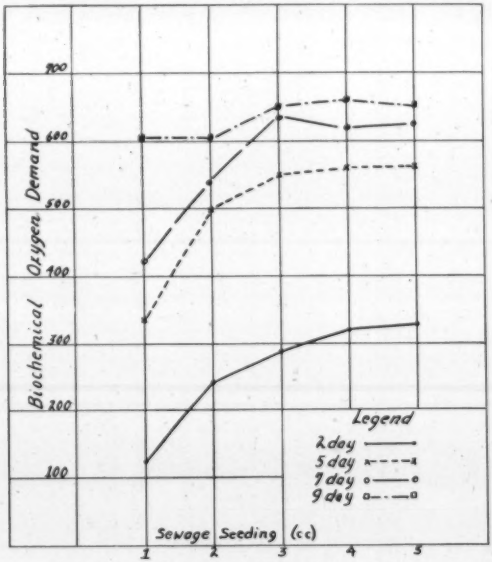


CHART III.—The B. O. D. of Seeded Lactose Solution.

extent as to be almost directly proportional to the quantity of seeding added. The final B. O. D. (20-day) appears to reach about the same value with all quantities of seeding. The lag which takes place in the first 5 to 7 days appears to be made up in the succeeding days of incubation.

Since this lag sometimes affects the 5-day period generally used for this test, it would appear that some further standardization is necessary in cases where seeding to B. O. D. incubation is necessary. Either there must be assurance that the optimum quantity of seeding has been added or the incubation must be carried on for a longer period.

Plant Operation

Activated Sludge Treatment Replaces Imhoff Tanks and Sprinkling Filters at Newark, N. Y.*

By Glenn D. Holmes

Consulting Engineer, Syracuse, N. Y.

Conspectus

In revamping the old treatment plant at Newark for the new process practically all of the existing structures were utilized advantageously. The new plant embodies a number of innovations.

This paper includes a brief description of the old and new plants, gives the reasons for selection of the activated-sludge process and presents a summary of the operating results to date.

The following unusual features are of special interest:

1. A Venturi flume and meter for measuring and recording sewage flows, operated by one float.
2. A grit chamber with velocity controlled by Venturi flume.
3. Activation by paddle-wheel aerators and diffused air.
4. Variable rate of return sludge with constant speed centrifugal pumps.
5. Utilization of gas from separate sludge digestion for power requirements of air for activation.
6. Recovery of heat from the gas engine to maintain optimum temperature of digestion tanks by circulating water through the cylinder jacket and heat exchanger. The hot exhaust gases of the engine are passed through the heat exchanger.
7. Five thousand cubic foot gas-holder, fully enclosed. The gas-holder well utilized as a sedimentation basin for the foul overflow liquors of the separate sludge digestion tanks. Temperatures of gas-holder maintained above freezing by the warm overflow from the digestion tanks.
8. Removal of sludge from the digestion tanks without venting or interfering with collection of gas.

Newark Sewer System

The village of Newark, about 35 miles easterly from Rochester, is a community of about 6500 population. The State School for Feeble

*Presented at the Spring Meeting of the New York State Sewage Works Association, Rochester, N. Y., June 10, 1933.

Minded contributes the sewage flow of an additional 1000 persons. Favorable transportation facilities by rail, highway and canal have attracted perhaps more than the usual number of manufacturing establishments for a community of this size.

Plans for the separate system of sewers and treatment plant were prepared in 1912 by the late James H. Fuertes, consulting engineer. Construction was completed and the plant placed in service in 1914. A few street inlets have been connected with the sanitary sewers which increase the sewage flow substantially during times of heavy rainfall. Infiltration adds a further burden during seasons of high ground water table.

Very noticeable fluctuations in the flow of sewage at the treatment

FIG. 1.—The Old Newark Plant. Screen Chamber in Foreground Followed by Grit Chamber and Radial Flow Imhoff Tank. The Sprinkling Filter in Background Is Operating at Maximum Head. Note the Poor Distribution. The Elevated Dosing Tank May Be Seen at Left of Filter Behind the Pumping Station.

plant are caused by two low lift pumping stations in sections of the village which could not be served by gravity sewers.

The Old Plant

The old plant was designed to treat 500,000 gallons of sewage per day (Figure 1). The total water consumption of the village was somewhat less than this and it was believed that it would be some time before all of the property owners would install sanitary conveniences and connect with the sewer system.

The old treatment plant included the following units: a screen chamber with coarse bar rack; a two-compartment grit chamber; a radial-flow Imhoff Tank; a pumping station; a dosing tank and two sprinkling

filters; a final settling tank; and an open sludge drying bed. (A duplicate bed was added later.)

The pumping equipment, consisting of two duplicate, direct-connected, motor-driven, float-controlled centrifugal pumps, elevated the Imhoff tank effluent from a well beneath the pumping station to the dosing tank. The total lift, including friction, was about 22 feet. The pumps were set at such elevation as to avoid a suction lift and the piping connections permitted either pump to be used for discharging Imhoff sludge to the drying beds.

Inadequate Treatment

Sometime before completion of the treatment works, arrangements were made for the village to dispose of the sewage of the State school. This placed a load on the plant from the start, not contemplated by the designing engineer. The increases in population of both the village and the State school, and still further increases in the per capita contribution of sewage, overloaded the treatment works to such an extent that, during recent years, inoffensive operation was no longer possible.

The plant effluent discharged into Military Run, a tributary of Ganargua Creek. At the time of constructing the Barge Canal, the State diverted the greater part of the flow of Military Run to the Canal. This diversion left little and at times no water for dilution of the treated sewage. Offensive conditions, resulting in litigations, developed along this small watercourse, which meanders through pasture lands to its junction with the larger stream.

A golf course adjoins two sides of the plant site. Several dwellings are in the neighborhood. Serious odors from the sprinkling filters, and perhaps more particularly from the open sludge beds, were frequently carried for a considerable distance and caused many complaints. Abatement of the nuisance became necessary.

Operating Troubles

An investigation of the plant in 1929 indicated very clearly that all of the units were of inadequate capacity. The grit chamber failed to prevent detritus being carried into the Imhoff tank, and caused trouble in removal of sludge. The flowing-through compartment of the Imhoff tank did not provide the necessary detention for good clarification, and the escaping solids clogged the sprinkling filters and caused pooling on the surface. The lower compartment of the Imhoff tank was too small for digestion of the solids, and it was necessary to remove the sludge to the drying beds, while in foul, putrid condition. This sludge when placed in the beds would not drain readily, and required an exceedingly long time for drying. Although the original drying bed area had been doubled, it was still much

too small. The odors from the exposed, decomposing accumulation carried far and were particularly offensive.

The spray from the sprinkling filter nozzles wetted only 26 per cent of the filter surface. (See Fig. 2.) This poor distribution resulted from insufficient elevation of the dosing tank, and from the rectangular nozzle spacing. Disintegration of the filtering material was a contributary cause of the pooling, previously described.

The old plant had been under the care of one man for many years, who seemed willing enough to listen to advice for improving operating condi-

FIG. 2.—The Old Sprinkling Filter. The Dark Circles Show the Limits of the Spray at Maximum Nozzle Discharge. Only 26 Per Cent of Surface Wetted. Nozzles on Rectangular Spacing. Golf Course in Background.

tions, but never took it seriously. He knew his child, and there was no need for a stranger to offer suggestions. He had some very amusing theories. The lifting of sludge from the lower to the upper compartment of the Imhoff tank was brought about by the moon, and occurred during certain phases—provided the sky was not overcast. Likewise, the position of Jupiter and Venus and the other planets accounted for the pooling on the filters, the non-drying of the sludge or for some particularly disagreeable odor.

The good man has passed to his reward, and the operator of the new plant must evolve his own theories for any misbehavior. It is up to him to find a better alibi, and there will be little time for star-gazing.

Choice of Process for Reconstruction

Studies and comparative estimates of cost were made of several alternative plans for the new construction. It was realized that severe criticism and censure were certain if the plan recommended did not prevent the recurrence of the disconcerting experiences with the old works.

The possibility of extending the collecting sewer and constructing a new plant in a more isolated location was found impractical on account of construction and operating costs.

The decision in favor of revamping the existing plant for the activated-sludge process rather than repairing the old works and constructing additional settling tanks, and sprinkling filter units, resulted from the following conclusions:

1. An activated-sludge plant, with intelligent operation, would insure an effluent of as good quality and perhaps of better appearance.
2. There would be less opportunity for unpleasant odors from the plant as a whole, or from any part of the treatment process.
3. Construction costs were found more favorable for the activated-sludge process, for the particular installation, for the reason that practically all of the units of the existing plant could be used advantageously for the new process with little expense for alteration.
4. The operating costs for activated sludge compare favorably since a gravity flow through the plant could be obtained, while pumping of all sewage was required for sprinkling filters.
5. Less of the plant site would be occupied by structures, leaving a larger area for landscaping and for improving the attractiveness of the grounds.
6. The necessity for more careful intelligent supervision of the activated-sludge process insures the employment of more experienced and competent operators.

The New Plant Units

The most important work in connection with the remodeling of the existing plant for the activated-sludge process included: Bar screen, with closer spacing; grit chamber of more efficient design; venturi flume and meter, for recording the volume of sewage treated; primary clarification tank, with sludge removal mechanism; aeration tanks of the paddle-wheel, diffused-air type; final clarification tanks with sludge-removal mechanisms; separate sludge digestion tanks, two units, reconstructed Imhoff tank and new structure; sludge storage and conditioning tank, provided

by covering the existing final settling tank; sludge drying bed by alteration of existing sprinkling filters and erection of glass enclosure; office, laboratory and equipment building furnished by alteration, repair, and enlargement of existing pumping station; laboratory equipment, for routine analysis; gas holder, enclosed to conserve temperature and to improve the appearance of the structure; equipment for utilization of gas and for furnishing air for activation; and grading and landscaping of the grounds, installation of floodlights for night illumination and the erection of a fence around the plant site (Figure 3).

Provision for the Future

The population of the village of Newark, and the number of inmates in the State school for feeble minded has increased at a remarkably uniform rate during the past decade, from 6200, in 1910, to 7650 in 1930. Recent enlargement of the State school makes provision for an increased number of attendants and inmates. The plant has been designed for a future population of 10,000, which will probably be ample for about 20 years, or until 1950.

Quantity of Sewage.—Gaugings of the sewage flow at the plant were obtained by means of a V-notch weir, and a water stage recorder, from July, 1929, to June, 1931.

A study of these records indicated the following flows for 1930:

Summer average	0.85 m. g. d.
Spring average	1.25 m. g. d.
Summer storms	1.5 m. g. d.
Spring storms	2.0 m. g. d.

For the 1950 flows, it was assumed that the summer average will increase in proportion to the increase in population, or 33½ per cent, or from 0.85 to 1.10 m. g. d. It will be observed that this is the equivalent of 110 gallons per capita per day.

It was further assumed that an effort will be made to relieve a portion of the storm water now reaching the sanitary sewers. The future quantities of sewage for 1950 for plant design were therefore taken as:

Summer average	1.10 m. g. d.
Spring average	1.50 m. g. d.
Summer storms	1.75 m. g. d.
Spring storms	2.25 m. g. d.

Design and Construction Details

Bar Screen.—The old grating was discarded and replaced with a bar screen having a clear spacing of 1 inch. The screen is 1 ft. 8 in. wide by 7 ft. 11 in. long, and is placed on an inclination of one on three.

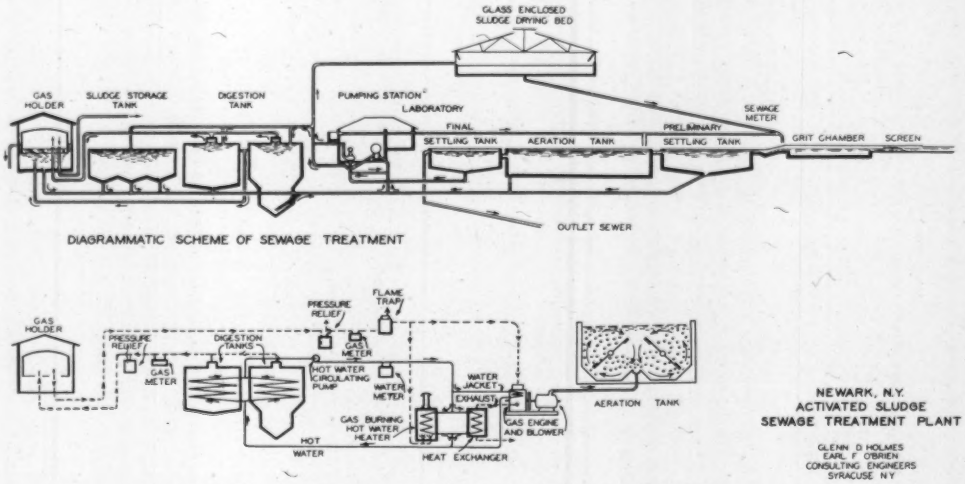


FIG. 3.—Diagrammatic Scheme for the Utilization of Sewage Gas.

The plans for the new construction did not provide for covering the old screen chamber. The accumulation of screenings and their containers at the entrance of the plant were found to be unsightly and an enclosure has recently been provided. This protection, particularly during inclement weather, will make the task of raking less arduous.

Grit Chamber.—The grit chamber has two compartments 46 ft. in length, of such cross-section as to maintain a velocity of about one foot per second for all flows. This desirable feature of velocity control is accomplished by the Venturi flume, which is placed at the end of the chambers (Figure 4). The flume causes the depth of flow through the chambers to vary in accordance with the head requirements for discharge through the flume.

Venturi Flume.—The Venturi flume has a rectangular cross-section throughout, a throat width of 12 in. and an over-all length of 14 ft. The flume is constructed in accordance with the "Improved" design, suggested

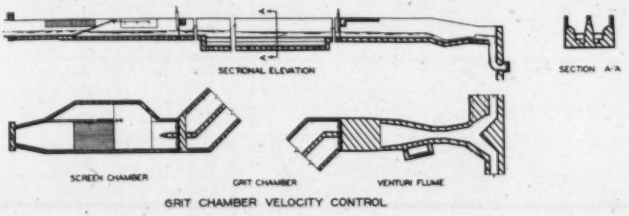


FIG. 4.

by Mr. Ralph L. Parshall, Irrigation Engineer of the U. S. Reclamation Service. The feature of special interest in connection with this design is the hydraulic jump produced beyond the throat (Figure 5). This prevents the complicated back-water effect of variable flow at the contracted section and permits accurate determination of the discharge with only one head reading. The formula for free flow discharge through the improved Venturi flume is:

$$Q = 4WH^{1.522W^{0.26}}$$

in which

Q = quantity in second-feet
W = throat width in feet
H = head, in feet, observed at a point distant upstream from the crest, two-thirds the length of the converging section.

This type of measuring device offers several advantages. Its accuracy is not affected by the deposition of detritus or floating matter, nor by sub-

mergence of crest less than 70 per cent. The over-all loss of head is less for a wide range between minimum and maximum discharges. A weir, orifice or standard Venturi meter could not have been installed at Newark to measure accurately both the maximum and minimum rates and secure a gravity flow through the treatment works.

The Sewage Meter.—An indicating, integrating and recording meter is installed in the office. The meter is actuated by a float operating in a stilling well which is connected to another well, built integral with the flume. The recording mechanism is driven by a Warren Telechron clock.

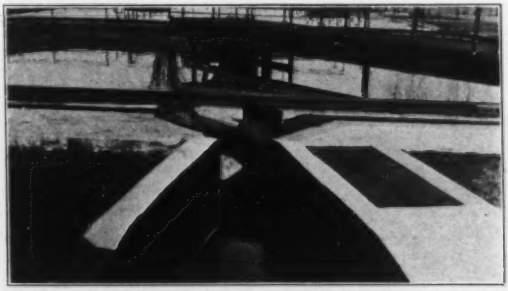


FIG. 5.—The Venturi Flume. Note the Hydraulic Jump Beyond the Contracted Section and the Division of Flow to the Inlet Channel of the Primary Clarifier. The Cover at the Right of the Flume Is Over the Stilling Well. The Metal Stop Planks (Two of Which Are Elevated) Are for Diverting the Flow Around the Primary Tank to the Aerating Tank.

TABLE I

DIMENSIONS, AREAS, VOLUMES OF TANKS AND STRUCTURES

Structure	Number Shape	Dimensions, Ft.	Surface Area, Sq. Ft.	Depth,[a] Total	Ft. Net	Volume, Total	Cu. Ft. Net
Primary Clarifier	1 sq.	45 x 45	1,953	9.0	8.5		16,617
Final Clarifiers	2 sq.	35 x 35	1,183	9.5	9.0		10,647
Aeration Tanks	2 ret.	27 x 75	2,025	14.0	14.0		25,813
Digester—Imhoff	1 cyl.	29.0 top 18.0 bot.		38.5	34.0	15,972	12,800
Digester—New	1 cyl.	30.0	168	23	18.1	7,742	12,800
Sludge Storage Tank	1 ret.	14 x 42	531	12	12	15,904	7,742
Gas Holder Well	1 cyl.	26.0		12.5	11.0		5,841
Gas Holder Lift	1 cyl.	24.0					5,000
Drying Beds	8 ret.	76 x 20	12,260				

[a] Side water depth.

Clarification Tanks.—The primary and final clarification tanks are equipped with Dorr traction mechanisms for sludge removal. (See Tables I and II for dimensions and capacities.) The discharge from the Venturi flume as it enters the primary tank (Figure 6), is divided into two equal portions which are again subdivided, insuring the same volume of flow through each of the four submerged inlet ports. Semi-cylindrical gratings form baffles in front of each port. This design in connection with the long effluent weir has prevented streaming.

A by-pass channel constructed integral with the north wall of the primary tank connects the Venturi flume directly with the aeration tanks,

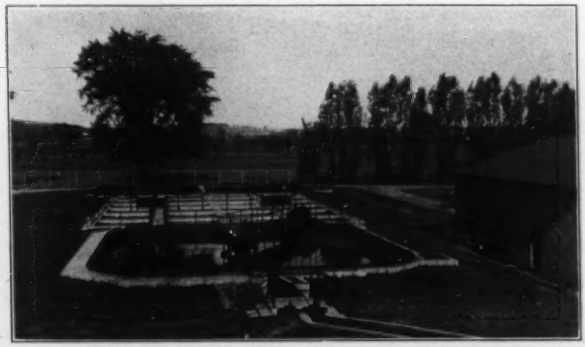


FIG. 6.—The New Newark Activated Sludge Plant in Operation, June 1, 1933. The Grit Chamber in Foreground Is Followed by Venturi Flume, Primary Clarifier, Aeration Tanks and Final Clarifiers. The Fence and Trees Are on the Line of the Golf Club Grounds. The Old Pumping Station, Remodeled for Housing Mechanical Equipment, Office and Laboratory, Is at the Right. The Head Box May Be Seen at the Far Corner of the Building. Note the Scum on the Upper Right Surface of the Primary Clarifier Being Removed by the Skimmer.

which permits unwatering of the clarifier for inspection or repair without interruption of the final process of treatment.

The effluent weir of the primary tank forms one side of a trough. Ports in the bottom of this trough connect with inlets of the aeration tank. Extending along the opposite side of the trough another weir, adjustable as to elevation, permits the discharge of clarified sewage directly to the outlet sewer of all flow in excess of 2.25 m. g. d., the maximum quantity for which the final or activated-sludge process is designed.

Aeration Tanks.—The aeration tanks consist of two units. (See Tables I and III for dimensions.) Paddles are attached to two shafts

TABLE II

DETENTION PERIODS AND SURFACE RATES PROVIDED SEPARATELY BY THE PRIMARY AND THE TWO FINAL CLARIFICATION TANKS FOR THE PRESENT AND FUTURE ESTIMATED SEWAGE FLOWS. IT IS ASSUMED THE FINAL TANKS WILL RECEIVE AN ADDITIONAL FLOW OF 25 PER CENT RETURN ACTIVATED SLUDGE

	Sewage Flow, M. G. D.		Detention Period, Hours		Surface Rate, G. P. Sq. Ft. Day	
	Present	Future	Present	Future	Present	Future
Summer Average	0.85	1.10	3.5	2.7	440	570
Spring Average	1.25	1.50	2.4	2.0	650	770
Summer Storms	1.50	1.75	2.0	1.7	770	910
Spring Storms	2.00	2.25	1.5	1.3	1040	1170

TABLE III

THE DETENTION PERIOD PROVIDED BY THE TWO AERATION TANKS, AND THE VOLUME OF AIR FURNISHED FOR ACTIVATION BY THE GAS ENGINE DRIVEN BLOWER, ASSUMING A 25 PER CENT RETURN OF ACTIVATED SLUDGE. THE MOTOR DRIVEN BLOWER WILL FURNISH ABOUT 10 PER CENT GREATER VOLUME OF AIR

	Sewage Flow, M. G. D.		Detention Period, Hours		Cu. Ft. Air per Gal.	
	Present	Future	Present	Future	Present	Future
Summer Average	0.85	1.10	8.85	6.82	0.61	0.47
Spring Average	1.25	1.50	6.00	5.00	0.41	0.35
Summer Storms	1.50	1.75	5.00	4.28	0.35	0.30
Spring Storms	2.00	2.25	3.75	3.33	0.26	0.23

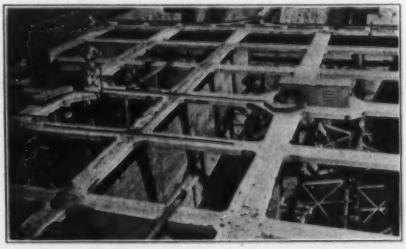


FIG. 7.—The Aerator Tanks Nearing Completion. The Paddle Wheel May Be Seen in the Compartment to the Right, Also the Chain Drive.

extending lengthwise in each tank, and are rotated by a 5-hp. motor through speed reducer and chain drives (Figure 7). Air is admitted through "Filtros" plates placed midway between the paddles and four feet above the tank bottom.

Sludge Digestion Tanks.—The two separate sludge-digestion tanks are equipped for gas collection, and for temperature control by circulation of hot water through 7 coils of two-inch galvanized wrought iron

pipe. The old final settling tank was remodeled for sludge storage and conditioning, but not for gas collection or temperature control. (See Table I for dimensions and capacity.)

Alterations of the existing Imhoff tank included the removal of the interior walls of the settling compartment and the baffles, increasing height of the outside walls to give added volumetric capacity and the construction of a gas-tight cover and gas hood. This old tank had a conical bottom and the sludge draw-off pipe extended through the lower compartment, preventing the economical installation of a stirring mechanism.

The new digestion tank is equipped with Dorr mechanism for agitation, breaking up of scum and for removal of sludge. Steel beams, encased in concrete, support the tank roof and the Dorr mechanism, obviating the

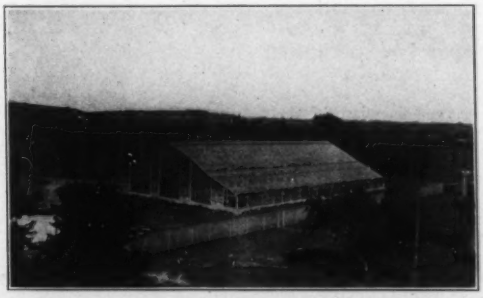


FIG. 8.—The Glass-Enclosed Sludge Drying Beds on the Old Sprinkling Filter. Compare with Fig. 1 and Note the Improvement Effected by Grading Around Old Walls. Golf Course at Rear of Enclosure.

necessity of unsightly truss construction. Both digestion tanks are placed below the general surface without additional embankment, which adds to the general appearance of the plant grounds.

Alterations of the existing final settling tank required increasing the height of the outside walls, the construction of a concrete cover and alteration of the piping connections. The tank is covered with earth, the surface seeded and, like the digestion tank, is not visible.

These three tanks provide a total of 3.2 cu. ft. per capita, future population, for digestion of sludge after making allowance for supernatant liquor. The piping arrangements permit operating the tanks in parallel or for either two or three stage digestion.

Gas Holder.—The gas holder has a capacity of 5000 cu. ft. (See Table I for dimension.) Gas is stored under 6 inches water pressure.

The well is placed below the ground surface, and the lift is fully enclosed. The superstructures are of hollow tile with exterior finish of stucco, and in keeping with all other buildings of the plant.

The capacity of the holder was determined from the assumption that one cu. ft. of gas per capita per day would be obtained from digestion of the mixed raw and activated sludges or from 7000 cu. ft. per day, shortly after starting operations, to 10,000 cu. ft. per day about the year 1950.

Sludge Drying Beds.—The existing sprinkling filter was reconstructed for sludge drying by removing the dosing tank, the nozzles, risers and the upper two feet of stone, resurfacing with 12 inches of graded gravel and sand and erecting a glass enclosure on the existing walls. (See Table I for dimensions.) (Figures 8 and 9.) Excess material from the

FIG. 9.—Interior of Glass-Enclosed Sludge Drying Beds, Steel Construction—Galvanized. Sludge Ready for Removal. Industrial Track on Center Line Each Bed. Side Sash Swing Inward and Operated by Hand Wheel at Side Entrance, Center of Enclosure.

excavation was placed around three sides of the old structure which was elevated above the ground surface. A trestle along the remaining side permits dumping of the dried sludge directly into trucks, or the sludge may be stored underneath the trestle, inconspicuously, until such time as disposal is convenient.

The total area provided for sludge drying is 12,260 sq. ft., or about 1.6 sq. ft. per capita for the present and 1.2 sq. ft. per capita for the assumed future contributary population.

The Pumping Station.—The pumping station required considerable alteration and repair to place it in suitable condition for housing the miscellaneous mechanical equipment and for the laboratory and office use. The old pump room was below the ground water table and the

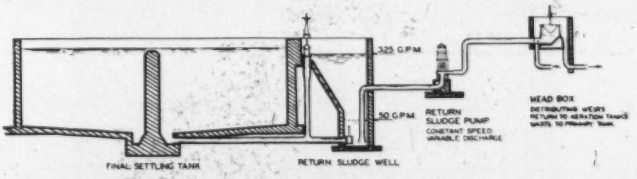
walls and floor leaked badly. Underdrains and waterproofing were required since it was desired to place the raw and return activated-sludge pumps at this elevation and avoid a suction lift. The building was enlarged to provide additional room (all below ground) for the gas control equipment, the gas-burning hot water boiler, the coal-burning hot water boiler and the coal bin.

The floor of the office and laboratory was raised to ground level to avoid the existing step at the entrance. The laboratory is provided with work bench, and adequate equipment for routine analysis.

Mechanical Equipment

The Primary Sludge Pump.—The primary sludge pump is of the variable stroke, displacement type, with maximum capacity of 4500 gallons per hour, against a head of 35 feet.

Return Sludge Pumps.—The sludge draw-off pipes from the final clarifiers terminate in vertical riser pipes with telescopic weirs in the



RETURN SLUDGE CONTROL

FIG. 10.

return-sludge wall (Figure 10.) The rate of sludge removal, which depends upon the elevation of these weirs, is readily adjusted by hand wheels mounted on valve stands. The return-sludge pumps remove the sludge from this well to the head box, from which any desired quantity is returned by gravity to the aeration tanks, or wasted to the primary clarifier, or the sludge storage tank. This division of flow among the several tanks is regulated by V-notch weirs at the head box, which are readily adjustable by hand wheels.

The return sludge pumps are 4-in. vertical centrifugal pumps with 6-in. suction and discharge connections, operated at constant speed by direct connected motors. These pumps have a capacity of from 50 to 325 g. p. m. when pumping against total heads of from 14 to 8 ft. The pumps operate automatically, at whatever rate the sludge is being withdrawn from the final clarifiers, the elevation of the liquid surface in the suction well rising or falling until the pumping head and pump capacity corresponds with the rate of draw-off from the clarifiers.

A flap valve is installed in the discharge line of each pump which is

made to break the electric current to the motor and stop the pump when the discharge falls below 50 g. p. m.

The Circulating Pump.—The circulating pump for hot water is placed in the return line from the digestion tanks. This small pump has a capacity of 15 gallons per minute against a total head of 20 feet. The piping connections and valves permit dividing the return water between the water jacket of the engine, the heat exchanger or the gas-burning boiler or short-circuiting any or all of the heating equipment. The circulating water may also be divided as desired between the two digestion tanks and the well of the gas holder.

The Sump Pump.—The sump pump handles wash water from the lower floor of the station, and from the underdrains of the building. The motor is automatically started and stopped by means of a float-operated switch. This pump has a capacity of 1500 gallons per hour against a total head of 15 feet, and discharges into the toilet connection above the Venturi flume.

The Gas Engine Blower Unit.—The blower is a Roots-Connersville positive displacement, horizontal double-lobe top discharge blower, with 6-inch pipe connections. It is mounted on a cast-iron base, and direct connected through flexible coupling with the Fairbanks-Morse Z type, 15-hp. gas engine, with high compression piston.

The unit was guaranteed to deliver 360 cu. ft. of free air per minute at 350 r. p. m. against a pressure of 5 pounds, the engine to have a fuel consumption not greater than 11,000 B. t. u. per brake horsepower at full load, 12,000 B. t. u. at three-quarters load and 14,000 B. t. u. at half load.

The Electric Motor Blower Unit.—The blower is similar to the above, mounted on a common base, and direct connected, with the 15 horsepower motor. This unit has a capacity of 400 cu. ft. of free air per minute at 690 r. p. m.

The Air Filters.—Two units of the Type E Compressor Filters made by the American Filter Co. were installed to insure clean air for the activated-sludge process. Each filter, when clean, has a capacity of 360 cu. ft. per minute, with a pressure loss not exceeding $^3/_8$ inch of water. These filters were first cleaned May 22, after about 7 months of operation, at which time the pressure loss was about 0.6 inch.

The Heat Exchanger.—The heat exchanger is a "Paracoil Exhaust Gas Generator," 16 in. in diameter and 10 ft. high. An insulating covering, 1 in. in thickness, of 85 per cent magnesia blocks, was placed on the exchanger and pipe connections. The recommendations of the manufacturer were followed in connecting the engine exhaust to the top of the exchanger. After certain trouble developed with the gas engine (which will be noted) the piping connections were reversed to permit a more direct and shorter connection.

The Gas Meters.—The gas meters are the Standard "Emco" iron body meters. The gas from each digestion tank is measured separately by a No. 1 meter before entering the gas holder. Gas used from the holder is measured by a No. 2 meter. Manometers, indicating water-pressure, are installed in all lines.

The Air Meter.—The air meter is of the orifice plate type, with indicating dial, and 7-day recording chart, calibrated to read the volume of free air per minute. The pressure gauge is of the single tube, Bourdon type. These three dials are mounted on a single pressed steel panel board. Air meters (orifice plate) of the manometer type, indicating the rate of air supply to each aeration tank are mounted on the tank walls.

An air draft manometer of the inclined tube type, graduated to read a maximum of 6 inches of water, is connected with the suction intake pipe between blowers and the air filters.

The Sewage Meter.—The sewage meter which has been described in connection with the Venturi Flume, was furnished by the Bailey Meter Company. This was the first integrating and recording device of the type manufactured for a Venturi flume. Comparatively little special work, however, was required in the shaping of a cam from the rating table furnished the manufacturers to adapt their standard meter for this use.

Construction

The work of construction and the furnishing and installation of the equipment was awarded under one contract to the Scott Brothers Construction Co., Inc., of Rochester, N. Y., Dec. 9, 1931. The final estimate given under date of Dec. 9, 1932, totaled $116,977.51.

The old plant was continued in operation during the construction of the new clarification and the activating tanks, and the grit chamber. The sludge storage and conditioning tank, on completion was used to store the partially digested sludge from the Imhoff tank, which was later used to seed the new digestion tanks.

Very shortly after discontinuing the Imhoff tank, the connection between the old screen chamber and the new grit chamber was completed, and the new primary tank placed in service.

Character of Sewage Treated

With the exception of an old combined sewer in one street, the sewage is brought to the treatment plant from a sanitary system. The sewage is comparatively fresh, and of more than average strength. Occasionally foul septic sewage with strong hydrogen sulphide odor is plainly noticeable about the screen and grit-chamber. At times the sewage has a pronounced red color which has not as yet been definitely traced.

An investigation in 1931, by Mr. L. H. Wright, City Engineer, indicated that there were only a few establishments contributing industrial sewage.

The water supply of the village, which is obtained from Case Creek, filtered and distributed by gravity, is extremely hard. An analysis June 30, 1932, gave a hardness of 257 p. p. m.

Plant Operation

The new activated-sludge plant was started in operation, October 1, 1932 (Figure 11). No more than the usual difficulties were experienced in starting a plant at this season of the year. The digestion tanks were seeded with old Imhoff tank sludge, which had been stored for several

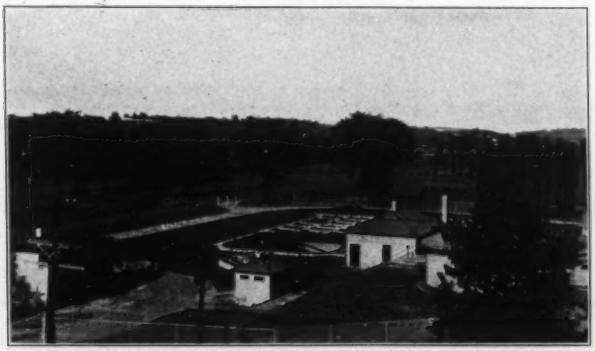


FIG. 11.—The Completed Plant. Old Store House Left Foreground. Screen House, Center Foreground. Gas Holder in Front and to the Right of Equipment Building. The Fence Bounds the Plant Grounds. Compare with Fig. 1 and Note Improvement in the Appearance of the New Treatment Works.

weeks in the storage and conditioning tank. The primary tank which had been in operation for some time had a large accumulation of sludge which had to be removed, and probably this sludge was transferred to the digester too rapidly. The digestion tanks started foaming the latter part of October. It was hoped the condition would correct itself, and it was two weeks later before lime was added. No serious foaming has occurred since (Figure 12).

The final tanks have behaved remarkably well, and only occasionally has there been trouble from a small amount of extremely fine floc passing out with the effluent.

Table IV presents operating data for the first week of each month from Nov., 1932, through May, 1933. Samples of sewage for analysis are collected each morning at 10 o'clock. The analyses given are the averages for the week preceding the date noted. An automatic sampler has been designed to collect a representative sample of the raw sewage, of a quantity proportional to the flow, every 15 minutes.

Except for the month of January and the first three weeks of February, the stability of the final effluent (to methylene blue) has been in excess of 20 days. Occasional samples which were not discarded at the end of 20 days retained their color for 30 to 40 days and longer.

The cost of operation for the period February 5 to May 5, exclusive of interest charges, during which period the gas engine operated continuously was $14.52 per million gallons.

TABLE IV

ANALYTICAL AND OPERATING DATA, NEWARK, N. Y., SEWAGE AND TREATMENT PLANT FIRST WEEK EACH MONTH SINCE STARTING OPERATIONS

Week Ending Sewage Treated, m. g. d.	Nov. 0.518	Dec. 0.601	Jan. 0.709	Feb. 0.633	Mar. 0.642	Apr. 0.89	May 0.899
Settleable Solids, Cc. Liter							
Raw	7.3	8.1	5.9	13.1	10.6	9.0	
Primary	0.3	0.2	1.2	0.5	0.7	0.9	
Final	Tr.	Tr.	0.2	Tr.	Tr.	Tr.	
Total Susp. Solids, P. p. m.							
Raw		309	237	465	351	245	
Primary		81	89	125	181	116	
Final		6	29	13	18	11	
Per Cent Removal							
Primary		74	62	71	48	53	
Final		98	99	97	99	96	
Stability, Days, Final Eff.	5	20	9	6	20	20	20
pH Raw Sewage	7.2	7.6	7.5	7.6	7.6	7.6	
pH Final Effluent	7.2	7.2	7.2	7.2	7.2	7.2	
pH Primary Sludge	6.8	6.4	6.4	6.3	6.4	6.3	
pH Digestion Tanks	6.5	7.0	7.2	7.2	7.2	7.2	
Air, Cu. Ft. per Gal.	1.19	1.36	0.53	0.73	0.94	0.61	0.58
Suspended Solids Aeration Tank, P. p. m.		1830	3157	2085	1605	1435	
Suspended Solids Aeration, Cc. Liter	925	832	666	472	450	257	
Sludge Ratio		2.2	4.7	4.4	3.6	5.6	
Gas from Digestion, Cu. Ft. per Day	2521	7817	8630	10,257	8721	8621	6600
Electric Current, Kw. Hr. per Day	22.9	23.1	16.0	11.4	11.1	10.7	7.4
Hours Gas Engine Run per Day	3.2	9.0	19.1	24	24	24	24
Hours Electric Blower per Day	20.8	24.0	1.6	0	0	0	0

TABLE V

SLUDGE PROCESS OF DIGESTION

Per Cent of Solids and Ash in South Digester

Depth Above Bottom Tank	Dec. 13, 1932		Feb. 14, 1933		Apr. 5, 1933	
	% Solids	% Ash	% Solids	% Ash	% Solids	% Ash
22.5	6.30	26.6	4.37	26.9	4.95	24.1
20.5	3.72	28.2	4.14	30.8	5.15	24.5
18.5	2.64	29.0	..	..	..	..
16.5	2.34	31.1	2.69	33.0	3.85	27.0
14.5	1.69	33.4	..	..	..	..
12.5	2.20	26.8	2.34	32.7	3.69	28.2
10.5	1.61	33.4	..	..	..	..
8.5	1.69	32.0	2.38	33.7	2.80	30.8
6.5	1.65	33.3	2.29	33.9	..	..
4.5	1.65	34.7	2.33	34.2	3.32	26.5
0.7	2.34	34.5	2.87	30.3	4.10	25.5
Average	2.20	31.2	2.80	32.0	3.80	26.9
Sludge Pumped to Tanks		17.5		17.5		17.5
Reduction in Volatile		54.8		55.5		42.6
Total Reduction Solids		45.3		46.8		35.2

The above analysis by Dr. A. J. Fischer of the Dorr Co.

FIG. 12.—The Activating Tanks During the Foaming Period Oct. 13, 1932. The Tanks on the Left Operating with 300 Cubic Feet of Air per Minute. The Right Tank with Excessive Foaming, 100 Cubic Feet of Air per Minute.

Unexpected Operating Troubles

More or less trouble is usually expected during the preliminary operation of a new plant and the operator or designing engineer who is able to overcome all of the difficulties successfully is fortunate. Most of the anticipated troubles at Newark have not materialized, but the plant is still in its infancy and time will tell the story.

The most vexatious experience has been in connection with the gas engine which drives the blower furnishing air for the activated-sludge process.

Continuous operation of the engine during any month reduces the power bill by half. Operating the electric blower for more than 15 minutes in any month doubles the demand charge for electric current.

The principal trouble with the gas engine has been due to pitting of the exhaust valves causing loss of compression. The gas has been unusually high in H_2S which burns slowly and is not fully consumed within the cylinder causing trouble in the exhaust piping and the heat exchanger. These troubles have been at least partially corrected by substituting new exhaust valves of higher heat resistance, increasing the temperature of the circulating water in the cylinder jacket from 120° to 150° F., and changing the exhaust hook-up to the exchanger. The heat exchanger developed a leak on June 2 and has been temporarily disconnected.

It appears that most of these troubles may be traced to the H_2S content of the gas and scrubbing may be necessary. A survey of the sewer system is to be undertaken in the near future to determine, if possible, the source of the sulphates. The water supply of the Village (analysis May 7, 1933) contains 57 p. p. m. total sulphates, the final effluent 146 p. p. m.

The hydrogen sulphide content of the gas has been determined a number of times by different methods. Due to lack of suitable apparatus, the results of the determinations, which indicate as high as 10 per cent and as low as 0.4 per cent by volume, are regarded as only approximate. More recent tests made in a Bunte gas burette by direct absorption with iodine-potassium iodide solution indicated 3.39 per cent hydrogen sulphide by volume while absorption in sodium hydroxide, addition of a known amount of iodine solution, acidification and back titration with sodium thiosulphate, indicated 2.43 per cent. These determinations are probably more nearly correct.

Plant Operation

The plant is being operated under direction of Mr. L. H. Wright, Village Engineer and Superintendent of the Municipal Board.

Mr. Thomas J. Smith, the Chief Operator, was Engineering Assistant to Mr. Harold W. Hobbs, our resident engineer, during construction. Mr. William Verdow, Assistant Operator, was employed by the contractor as operator and repair man on mechanical equipment.

The writer desires to express his appreciation for the coöperation and assistance given by Dr. A. J. Fischer of the Dorr Company who has spent some little time at Newark advising the attendants regarding operation of the plant and giving instruction in the analytical laboratory work.

The plans for the work were prepared, the construction supervised, and the plant is being operated under direction of the writer and Mr. Earl F. O'Brien, Associate, Consulting Engineers of Syracuse, N. Y.

Sewage Aeration by Diffused Air*

BY FRANK C. ROE

Sanitary Engineer, The Carborundum Company, Niagara Falls, N. Y.

The past twenty years have witnessed a remarkable change and improvement in all forms of sewage treatment and in the types of equipment used therefor. Aeration of sewage and the activated-sludge process have undergone many improvements, particularly in the development of better aerating equipment. This paper deals with the progress in sewage aeration and the essential features and development of the air diffuser mediums which are employed.

Activated-Sludge Treatment

The activated-sludge process has experienced an ever expanding and successful life since its inception two decades ago. Many improvements in the process have been achieved; also, several types of mechanical aerators have been devised and used in small plants with success, but the diffused air method of developing and maintaining activated sludge has established itself as the standard, especially for larger plants.

The most important progress in design of aeration tanks used in the activated-sludge process has been the establishment of the spiral-flow type as economically superior to the early ridge-and-furrow type. This generally accepted design has been partially responsible for a change in the properties of the diffuser mediums required. With the earlier ridge-and-furrow design it was believed, and correctly so perhaps, that the greatest share of the oxidation came from the rising air bubbles. Thus, the diffusion of small bubbles to secure maximum oxygen absorption per unit volume of air was demanded and was supplied by small pore, low permeability diffusers.

With the advent of spiral-flow aeration, it has been found that larger bubbles delivered from higher permeability diffusers are satisfactory, although in reality there is but little difference in the size of bubbles discharged from the various grades of diffuser media. Some air may possibly be wasted by large bubble diffusion but the pressure required is less because the larger pore diffusers have lower frictional resistance. Beyond this, the indications are that the spiral-flow design requires about 25 per cent less air than the ridge-and-furrow design.

Large bubbles are effective in maintaining adequate transverse velocity across the aeration tank bottom in excess of the minimum requirement of $1^1/_4$ ft. per second. The greater velocity of larger bubbles is also re-

*Presented at the Spring Meeting of the New York State Sewage Works Association, Rochester, N. Y., June 9–10, 1933.

sponsible for a high overturning effect with a correspondingly high degree of surface aeration, as anticipated by the spiral-flow design. The larger pore diffusers providing large bubbles do not clog as readily as the fine pore diffusers.

One possible disadvantage of spiral-flow aeration in comparison with the ridge-and-furrow type is short-circuiting of a dead-water core assumed to exist on the longitudinal axis of the sewage flowing spirally through the aeration tank. A recent improvement has been devised to break up this "core," consisting of transverse rows of diffusers at intervals, from which the air discharge in effect forms a series of "baffle walls" during operation.

Early tanks employing ridge-and-furrow aeration were generally greater in depth than in width. When the spiral-flow design came into use, a

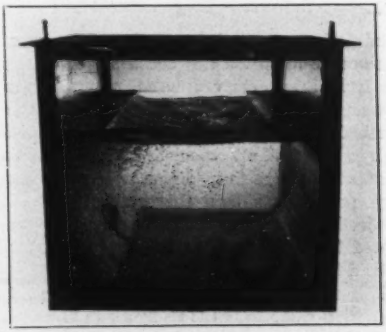


FIG. 1.—Illustrating Efficiency of Wide Aeration Tanks.

square cross-section was employed with success and recent experience has shown that greater widths than depths are possible. This is obviously an important improvement from the standpoint of both construction and operation cost. Wide aeration tanks are lower in cost per unit of volume because of the reduced total wall length. Greater benefit is derived from surface aeration, indicating a reduced air requirement per gallon of sewage. As an experiment, a division wall was removed between two aeration tanks at the North Side plant of the Sanitary District of Chicago, making the tank approximately 33 ft. wide with a 15 ft. liquor depth. This has been successfully operated using only the two rows of diffusers formerly employed in one 16 ft. wide tank. (See Fig. 1.)

Another development has been the combination of mechanical and air-diffusion aeration. A combined paddle-wheel diffused-air type is used to

obtain circulatory flow. Over-all power requirements are claimed to be low. This method seems to be particularly suited to smaller installations where the equipment investment would not be large.

Tanks shallower than approximately 15 ft. are uneconomical in construction and greater depths increase the cost of power for compression of air. This phase of design is controlled to some extent by anticipated air requirements and subsequent power cost.

In activated-sludge treatment, local conditions and sewage strength govern the period of aeration and the air requirements. Strong sewage requires either longer aeration than fresh dilute sewage or the application of more air per unit volume of sewage. If the power cost for air delivery

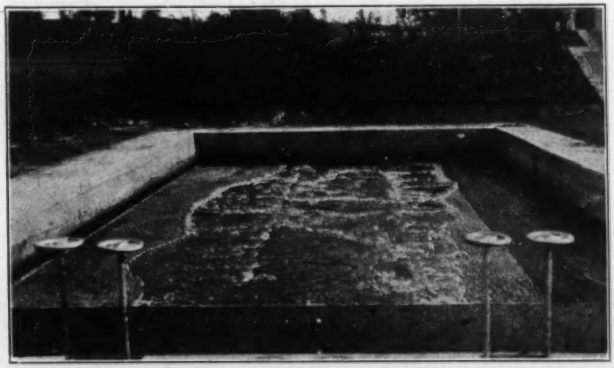


FIG. 2.—Springfield, Illinois, Pre-Aeration Unit for Grease Removal.

is low, a short aeration period will save on construction cost and capital charges. Conversely, high power costs warrant longer aeration periods.

Where advantage has been taken of the design improvements already noted, average periods of aeration under normal conditions are about six hours and the average air requirement is about 1.0 cu. ft. per gallon of sewage. The area of diffusers required is determined by the expected quantity of air discharge and the economic pressure loss allowable. However, there seems to be a minimum effective diffuser area, from which air can be delivered efficiently in the spiral-flow type of tank, which is approximately ten per cent of the tank area.

The cost of power for compression of air is the most important economic factor of activated-sludge plant operation. The practice at Birmingham, England, several plants in Germany and a few places in the United States

(notably Newark, N. Y., and Springfield, Ill.), offers a suggestion not to be disregarded. Gas engines have been installed in these places which utilize the gas from sewage sludge digestion. Some of them are claimed to generate all power required for aeration and other plant uses. The idea is chiefly confined to gas engines directly connected to the air blowers.

Pre-Aeration

While the activated-sludge process of oxidation or secondary treatment has flourished, additional sewage aeration practices by means of air diffusion have developed. Perhaps the most important of these is pre-aeration of raw sewage, the primary function of which is grease removal. Emulsified particles of oil and grease adhere to the small rising air bubbles and are carried to the surface where a scum is formed.

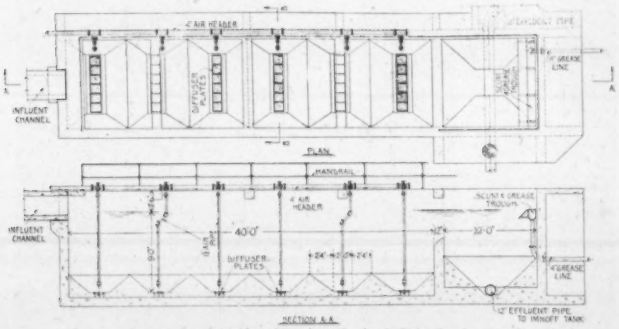


FIG. 3.—Pre-Aeration Tank, Whittier, California.

A special skimming compartment may be added to the pre-aeration unit if Imhoff tank treatment, for example, follows. If settling tanks with equipment adapted to skimming follow, the scum may be allowed to flow to said settling tanks for collection (Figure 2).

Pre-aeration is also invaluable in reducing odors and "sweetening" the sewage, especially when it is very stale or septic. Where the activated-sludge process of secondary treatment is not employed, pre-aeration for odor control alone may be of value in preventing odors from permeating the entire plant.

In addition to grease removal and odor control, pre-aeration is of positive benefit in improving the efficiency of preliminary settling. As high as 80 per cent removal of suspended solids has been achieved in settling tanks as a result of pre-aeration, with an equally remarkable reduction of B. O. D.

Furthermore, the elimination of high fat content in settled sludge is helpful for proper digestion either in Imhoff tanks or separate sludge digestion tanks.

A modification of the ridge-and-furrow type of design appears to be well adapted to pre-aeration since efficient grease removal depends upon maximum distribution of rising air bubbles. For the same reason small bubbles in large numbers, as obtained from low permeability plates, are best suited to the process.

Detention periods for pre-aeration vary from 10 to 30 minutes and the air requirements from $^1/_{20}$ to $^1/_{10}$ cu. ft. per gallon of sewage (Figure 3). Diffuser areas of about ten per cent (10%) of the tank area are adequate.

A unique grease removal design has been developed by Mr. H. L. Thackwell, Consulting Engineer of Tyler, Texas, which is being incorporated in the plant under construction at Tyler. The unit has an air-tight roof and application of a vacuum over the sewage results in diffusion or aspiration of fine bubbles from submerged diffuser tubes. Air at atmospheric pressure is supplied to the interior of the tubes.

Chemical Methods of Treatment

Quite a few new ideas in sewage treatment involving chemical methods have been proposed recently, chiefly for precipitation of solids and stabilization of effluent. Many of these methods definitely incorporate aeration by means of diffusion as part of the process while other methods are improved thereby.

A pre-aeration period will condition sewage to make the use of chemicals more economical and effective, particularly if the sewage is stale or septic. Such treatment will also provide excellent mixing of the chemicals used and will accomplish most of the previously mentioned advantages of pre-aeration.

One of the proposed chemical methods employs air diffusion to maintain the iron salt used for coagulation in its ferric state when it is applied to the raw sewage. Only a five-minute aeration period appears to be necessary, with an air requirement of about $^1/_{40}$ cu. ft. per gallon.

Another process employs aeration by diffusion to oxidize a ferrous salt to the ferric state, thereby making possible the use of a low cost chemical. In this process lime is also added with return sludge to an aeration or flocculation tank of the spiral-flow type, the iron then assuming the ferric hydroxide form. An aeration period of 20 to 30 minutes is required with about $^1/_{12}$ cu. ft. of air per gallon of sewage.

Miscellaneous

Among the miscellaneous applications for aeration in sewage treatment perhaps the most important is pre-oxidation of trickling filter influent.

The most notable example of this in America is at Decatur, Illinois, where a 2½-hour period of aeration has increased the filter capacity to three times its designed capacity. Operation may be with or without sludge return. Spiral-flow design is utilized, the air requirement being approximately 0.4 cu. ft. per gallon.

Trickling filter auxiliary-aeration by air diffusion is also practiced at Birmingham, England, and Moscow, Russia. At Moscow, a 30- to 60-minute period of aeration has made possible an increase of filtering rate of four times the normal rate.

A unique process has been developed by Mr. Clyde C. Hays, City Chemist of Waco, Texas, which consists of aeration in two stages of stone contact beds, one being a coagulation stage and the next an oxidation stage, with a clarification unit between stages. A final settling tank follows the second stage. Air in this case is introduced under the stone beds to increase and maintain the life of the biological organisms existing in the gelatinous stone film.

Channels conducting activated sludge, or the sewage and sludge liquor, are generally provided with air diffusers in their bottoms to maintain aerobic conditions and prevent settling. In fact, channel aeration is employed advantageously in all types of sewage treatment processes because it is most effective in accomplishing an even distribution of flow and suspended solids to the inlets of settling tanks on which the channels border or where they terminate.

Final or post-aeration by air diffusion is useful where removal of solids by any process is effective, but where the dissolved oxygen content of the effluent has not been raised sufficiently to discharge into a low flow stream or dry ditch.

Diffuser Mediums—General

The general types of porous air diffuser plates adopted early in the life of the activated-sludge process continue to be utilized, although many improvements have been made as important properties have become recognized. In England and Canada, porous diffusers made of a special lava-like material, usually about 36 in. long and 8 in. wide, furnished in cast-iron containers, are the type most commonly used. In the United States, 12 in. square plates have been standard; four to ten being set together in troughs, precast concrete holders or aluminum containers. "American" plates are made of grains of ground quartz or fused crystalline alumina, bonded together at high temperature by means of silicate and ceramic bonds, respectively.

The most outstanding innovation in diffuser mediums has been the development of the porous tube. The use of tubes has been confined to the United States; and to the East for the most part. Because assemblies

can be removed individually and quickly, while the plant is in operation, tubes offer certain definite advantages for the smaller size plant, say, of 2 m. g. d. capacity and less. Such plants rarely have sufficient auxiliary capacity to enable a complete aeration unit to be cut out of service for cleaning of diffusers or repairs. This is not only because the sewage would have to be aerated at a high rate in the remaining units but because the volume of activated sludge normally existent in any unit which is temporarily cut out should be retained for use when said unit is put back into service.

The development of porous diffuser tubes, which are made only of the fused crystalline alumina material, is an outgrowth of perforated pipe diffusers. Perforated pipes have been used in a few places but porous diffusers are about three times more effective because of the smaller bubbles per unit volume of air emitted.

Tubes are often installed in an elevated position about four feet below the liquor surface, thus reducing the pressure requirement appreciably. When this is done, it is proper to install a longitudinal baffle wall next to the tubes, open at the bottom. This idea was developed and patented by Mr. Henry E. Elrod, Houston, Texas. The baffle insures positive circulation and over-all economy appears to be effected even though more air may be required than when diffusers are at the tank bottom.

Diffuser Mediums—Required Properties

Permeability.—The basic property of diffusers is their ability to discharge air under pressure at a definite rate. This is a capacity factor properly termed "permeability." For convenience of testing, it has been specified as, "that quantity of free air in cubic feet per minute which will pass through one (1) square foot of area of the plate or tube, when dry at 70° F., under a pressure equivalent to two (2) inches of water."

Permeability is the proper capacity term and is not to be confused with "porosity" which is merely a measure of the pore volume per unit diffuser volume, expressed in per cent. The porosity of various grades of diffusers is more or less constant.

Permeability varies with the diffuser pore size or size of air bubble required and is essentially a variation in the size of grain used in the manufacturing process.

Every diffuser must be given the permeability test and the rating to the nearest $^1/_{10}$ cu. ft. stenciled thereon. Similarly rated diffusers are packed together for convenience of installation.

Uniformity.—The distribution of air discharge must be uniform over the entire surface of a plate or throughout the entire length of a tube. Uniformity of diffusers is entirely a function of careful and exact manu-

facturing processes and control. It is checked on a percentage of all plates or tubes made for an installation by an observation test. The plate or tube is barely submerged in water and air passed through it at a low rate (Figures 4 and 5). The diffusion is uniform if no areas exist where the emission of bubbles is greater or less than the apparent average discharge.

Low Frictional Resistance.—The drop in air pressure when air is passed through a diffuser medium must be as low as possible. Even though this factor is relatively small compared to the total pressure required, it is important because of the cumulative saving effect. Modern administration of sewage works demands that every possible improvement of efficiency shall be employed.

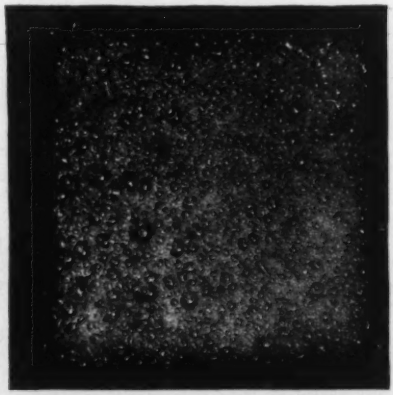


FIG. 4.—Distribution of Air through Porous Plate.

Frictional resistance decreases as the permeability or pore size of diffusers increases. In other words, more power is required to diffuse small bubbles into sewage than large bubbles.

The writer's experience with diffusers of the fused crystalline alumina type indicates that high porosity or high percentage of pore space will contribute to low frictional resistance. Also, a thorough coating of the individual grains of the diffuser structure with the bond ingredient appears to be helpful in obtaining low pressure loss.

Closeness to Specified Permeability.—It is essential to have all diffuser plates or tubes in an installation as near as possible to one prescribed permeability rating. This guarantees a similarity of bubble size and

similar aeration in all aeration units of a plant. Beyond this general requirement, it is absolutely necessary that all diffuser units controlled by each air valve be of a similar permeability rating, as explained hereinafter under "Installation."

Strength.—The physical structure of diffuser plates must be such that they will support the usual head of sewage and sludge liquor with an ample factor of safety. This requirement is met satisfactorily by the known types of plates in use, especially by the fused crystalline alumina type, the strength of which is an inherent property.

Strength tests are very often required by specifications and are conducted on a percentage of plates at the point of manufacture. As

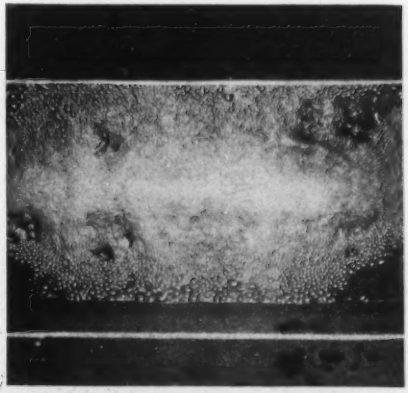


FIG. 5.—Distribution of Air through Porous Tube.

tubes are not subjected to any appreciable stress in operation they are not tested, although they are equally as strong as plates.

Stability and Durability.—Both the grain and bond ingredient from which diffuser plates and tubes are made must be inert to the action of such acids and alkalies as are found in sewage. All diffuser mediums now available meet this requirement.

Diffuser Installation

A promising improvement in diffuser plate installation is the aluminum container recently developed by Mr. A. A. Burger of Geo. B. Gascoigne's office, Cleveland (Figure 6). Plates are wedged into place over a rubber

gasket and are easily released for cleaning or servicing of any nature. This should be an advantage over the practice to date whereby plates are cemented in place over troughs in the aeration tanks or into cast iron or precast concrete containers, provided the rubber gasket and aluminum container remain unaffected by contact with the sewage and air.

Tubes are installed in pairs on either side of a tee connecting with the air supply. A single assembly rod on the inside of the tubes between gasketed end flanges as now used is a decided improvement over the original design of four assembly rods on the outside of the tubes between end flanges.

The prime requirement of diffuser installation is that of installing only diffuser plates or tubes of similar permeability rating on each air supply line. It is important that all diffusers controlled by a single valve be at the same elevation. This must be carefully watched in elevated diffuser tube installation, where a slight variation in elevation affects diffusion materially.

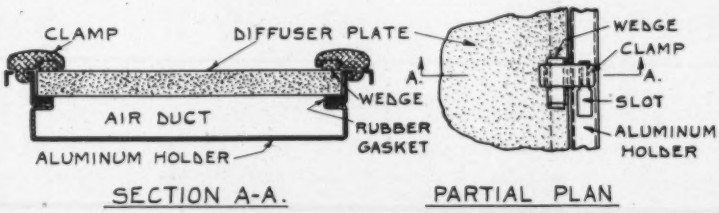


FIG. 6.—Burger Plate Holder.

Diffuser Operation

The chief subject of interest concerning the relation of diffuser media to satisfactory operation of aeration units is that of sources of clogging and methods of cleaning.

Rotary air blowers are now used almost entirely rather than reciprocating compressors, thus reducing the quantity of dirt and oil to be removed, and improving the efficiency of air filters. Ineffectiveness of filters means clogging of the air side of plates or tubes with oil and inorganic material.

Interruption of aeration is another source of clogging, as liquor immediately filters through the diffuser wall, carrying sludge particles with it. Repetition of this will obviously cause clogging as the pores offer tortuous passages which are bound to retain some of the material lodged therein when air flow ceases.

Quite often a film of organic material has been found to form on the diffuser surface and even grow into the pore structure. Clogging of this nature cannot be prevented and cleaning is the only answer.

Methods of cleaning plates in place are as follows:

1. Scrubbing with hydrochloric acid solution with intermittent air discharge.
2. Dissolving of $^1/_{10}$ lb. of lye per sq. ft. of diffuser area in $^1/_2$ or 1 in. of water over the plates; then shutting off the air and allowing solution to penetrate the structure.
3. Burning out with a blow torch (only applicable to top side clogging).
4. Providing a period of rest while totally dry.
5. Chlorine treatment.

Success of any of the above methods is dependent upon regularity.

The greatest success in cleaning diffusers is obtainable when they are removed. The best method is heating them in an oven to approximately 700° C. which will burn out the organic material and carbon. Acid pickling is also effective. Both of these methods indicate the advisability of using containers permitting easy diffuser removal. This is one of the original advantages of tubes and is now possible with plates.

Conclusions*

Because so many advances have been made in sewage aeration design and diffuser equipment it is felt that the foregoing outline of present-day practice is essential to a clear conception of the many factors involved. General improvement and economy of aeration design with a standardization of diffuser specifications is the ultimate objective.

Discussion*

BY A. B. HOLMSTROM

The Norton Co., Worcester, Mass.

Mr. Roe has given a very excellent description of the various uses of diffused air in the treatment of sewage.

Two years ago, I had the pleasure of visiting a number of sewage plants in England. I thought, therefore, it might be interesting for you to know the opinion of English engineers on some points that have been brought up in Mr. Roe's paper.

The activated-sludge method of sewage treatment has been used generally in the British Isles for years. There are four general systems in use in England. One type uses paddles and very shallow tanks. Sheffield is the most notable plant of this type.

A second type uses mechanical means of agitation. This type is in use at Birmingham.

Presented at the Spring Meeting of the New York State Sewage Works Association, Rochester, N. Y., June 9–10, 1933.

The third type uses diffuser plates exclusively; Birmingham's latest plant is of this type. To me the Birmingham plant was the most interesting plant in England. It has many types of installations. Its floating concrete gas collectors on separate digestion tanks provide enough gas for gas engines to develop 700 hp.

The fourth type uses a combination of the paddle system with diffuser plates. London's latest 10,000,000-gallon-a-day plant uses this system because the London engineers considered that it produced the least quantity of sludge. I had the good fortune of visiting this plant the day it started operation. The most interesting feature of the design was that of the shallow tanks. One tank is superimposed on another to reduce cost of pile foundation. An air pocket is maintained over the entire surface of the lower tank. In order to bring all the sewage in contact with the atmosphere in an equal length of time, the sewage is allowed to flow from a lower tank up into a higher tank and then again down into a lower tank. Provision has been made for the use of diffused air in connection with these shallow tanks if found necessary.

Mr. Roe discussed the ridge-and-furrow type versus the spiral-flow type. British engineers whom I met consider the ridge-and-furrow type more satisfactory than the spiral-flow type. The latest plants in Birmingham and London have adopted the ridge-and-furrow type.

I discussed this phase with various British engineers. One ventured the opinion that spiral-flow type might be satisfactory in connection with the dilute sewage that we have in the United States but was not satisfactory with the much stronger sewage encountered generally in Great Britain. One even went so far as to predict that we, in the United States, would revert some day to the ridge-and-furrow type.

Mr. Roe has mentioned permeability of plates. I think we have worried too much about the size of the air bubbles. I believe that we are now in agreement that the bubble size, as far as porous mediums are concerned, is not a factor in treatment by aeration. We have found that plants that use plates of higher permeability, with consequently larger pore size, have less difficulty from clogging than plants using plates with lower permeability.

An accelerated life test, conducted by a plant of this country, showed the per cent permeability loss was considerably higher for plates of low permeability and considerably less in high permeability plates.

Clogging is the main factor which determines the life of a plate. You can definitely increase its life by using plates of higher permeability.

Another point which Mr. Roe emphasizes in his paper is the importance of frictional resistance of porous mediums. Again there is an advantage in selecting a plate of higher permeability. For instance, we find that the friction loss through a plate of 20 permeability is about 7 in. of water

whereas a plate of 40 permeability will have a pressure loss of $2^1/_2$ in. of water.

What does this mean in dollars and cents?

Mr. McMillan, Assistant Engineer of the Sanitary District of Chicago, reported in an article in *Engineering News Record*, August 2, 1932, that it has been estimated that for each one-tenth lb. per sq. in. of pressure saved at a proposed plant of the Sanitary District of Chicago, a saving of about $3000 a year in cost of power would result. On this basis, it would mean that this plant would save in power per annum $4820 if it used a 40 permeability plate as against a 20 permeability plate.

Because of the savings which are possible with higher permeability plates and the increase in life of higher permeability plates, we recommend a permeability of 30 or higher.

Report of Committee on Sewage Sampling*
New England Sewage Works Association

BY

C. C. CARSON, Hartford, Conn. L. H. GEER, So. Manchester, Conn.
S. DEM. GAGE, Providence, R. I. M. C. WHIPPLE, Cambridge, Mass.
ROY S. LANPHEAR, Worcester, Mass., *Chairman*

Introduction

The Committee on Sewage Sampling appointed at the 1931 Annual Meeting of the New England Sewage Works Association realizes the impossibility of formulating any schedule of sampling of sewage and sewage treatment plant effluents which will serve the large and small plant equally well. Many of the small plants employ no night attendant and have no permanent or accurate method of measuring the volume of flow. Without laboratory control to some extent, there is lack of interest in the matter of accurate or representative sampling of influent and effluent.

The larger plant equipped for laboratory control requires collection of representative samples as an essential element of the control function. There exists a great lack of uniformity with respect to sampling and, undoubtedly, much published laboratory data is based upon analyses of samples which are not representative of plant conditions or results of operation. In many cases, definite conclusions are drawn from laboratory results upon such unrepresentative samples. This report is presented for consideration as an aid in encouraging improved uniformity of sampling at all sewage treatment plants or outlet sewers.

Collection of Representative Samples

The purpose of collection of samples of sewage, sewage effluent and trade wastes is to obtain a representative sample of the liquid for use in making a laboratory examination. Since a laboratory examination is expected to disclose the character of the material being sampled, it is absolutely essential that the sample be so collected that it will be representative of the sewage, sewage effluent or trade waste being sampled.

In order to formulate a program for the collection of the representative samples, it is necessary to bear in mind the following facts:

1. Changes in volume of flow.
2. Changes in character throughout the period of sampling.
3. Fair sampling of the flowing liquid with respect to the correct proportion of suspended and dissolved solids content.

* *Presented at the Spring Meeting of the New England Sewage Works Association, Woonsocket, Rhode Island, May 1, 1933.*

4. The laboratory examinations of samples of sewage and sewage effluent are made very painstakingly and with a degree of accuracy which probably far exceeds that which it is possible to obtain in sampling.

5. These laboratory results are usually taken at their face value as being absolutely correct with no reference to the method by which the samples were collected.

It is therefore apparent that as much care as possible should be given to the collection of sewage and sewage effluent samples so that the portion upon which the laboratory examination is to be made will be reasonably representative of the sewage or sewage effluent sampled.

Unless affected by the presence of storm water, ground water or the intermittent discharge of large quantities of industrial waste liquors, the volume of flow of sewage generally changes uniformly throughout the 24-hour period. The maximum rate is generally from three to four times the minimum rate of flow. Saturday and Sunday flows are usually slight exceptions.

Measurement of Sewage Flow.—The operators of all sewage treatment plants which are not provided with permanent means of accurately measuring the sewage flow should be supplied with data concerning the rate of flow in some conduit or channel at the plant in such manner that the depth of flow can be roughly interpreted in terms of quantity. With such data, the small plant operator is in a position to collect the proper size of samples over any period of time.

Storm Water and Ground Water in Sewage.—During such times as the sewage contains storm water or ground water with resulting increase in the usual volume of flow, sampling should be done in the usual manner with (1) the use of larger or additional containers for composite samples or (2) the proper change of the size of sample which will avoid the use of abnormally large containers for composite samples.

Industrial Wastes in Sewage.—When industrial waste liquors are discharged reasonably uniformly into the sewage throughout a large part of or the entire 24-hour period, the proposed methods of collection of representative samples of sewage should suffice. When such wastes are discharged in large quantities, or so-called "doses," intermittently throughout the 24-hour period, no method can be proposed which will result in the collection of a representative sample of sewage. The use of an automatic sampler, taking small and frequent samples to make a composite sample represents the closest attainment of a fair sample.

When industrial waste liquors are intermittently present in the sewage, it is recommended that special investigations be made concerning these liquors by frequent collection of sewage samples which can be composited during the period of their presence in the sewage.

Industrial Waste Liquors.—Samples of industrial waste liquors are

usually collected during investigations pertaining to their discharge into bodies of water or into sewage, which may or may not receive treatment. Such a sample may be (1) a catch sample, (2) a composite sample collected during the discharge of a particular portion of the waste or (3) a composite sample collected during a set period of time up to and including the entire 24 hours. Portions of composite samples should be collected with reasonable frequency and as nearly as possible in proportion to the rate of discharge of the waste at the time of collection.

Collection of Unscreened and Screened Sewage Samples

Unscreened sewage, unless well comminuted, is difficult to sample accurately. Therefore, where preliminary treatment of sewage is provided by grit chambers and screens, or only the latter, the sewage should be sampled following such treatment and previous to any subsequent treatment.

Where it is desired to determine the suspended solids content of the raw sewage previous to screening or grit chamber treatment, an accurate estimate may be made by determination of the weight of screenings and grit removed per unit volume of the raw sewage.

Unscreened sewage should be sampled as follows: A considerable portion of the sewage should be deposited from the collection dipper into a pail or other large container, well mixed and sampled according to one of the methods given below.

Methods of Collection of Samples

Excepting where automatic samplers may be in use, composite portions of any representative sample of sewage or sewage effluent should be collected by using a dipper which should be at least 6 in. in diameter and not less than 4 in. in depth. This sampling dipper should be provided with a handle of sufficient length to permit lowering it well into the sewage or effluent. The dipper should be agitated so as to avoid the collection of top liquid.

In channels, the dipper should be lowered to approximately two-thirds of the depth of the liquid. Where sampling stations are located in channels of considerable width, the point of collection of samples should be rotated across the channel. Channel and conduit bottoms should be kept clean from sludge and growths at sampling places. No samples should be retained which, in the knowledge of the sampler, are liable to contain bottom deposit nor should samples be retained which contain only surface liquid.

Samples to be used for the determination of dissolved oxygen should be collected according to the method described in "Standard Methods of Water Analysis."

Suitable dippers should be used for collection of a sample from a shallow depth of liquid, using, where necessary, an intermediate container for mixing to obtain the required quantity for any composite sample.

The measuring dipper should be wide mouthed and of shallow depth, and should be used by dipping into the liquid contained in the sampling dipper or large container in a manner similar to that described for use of the sampling dipper.

Representative samples of sewage and sewage effluent can be obtained when collected according to one of the following methods:

1. Samples may be collected proportional to the volume of flow at the time of collection and deposited in a container to form the 24-hour composite sample.

2. Samples may be collected in sufficient quantity, stored in a refrigerator or ice-box, and the composite sample made at the end of the sampling period according to the volume of flow at the time of collection of the separate samples.

3. Where it is impossible to proportion according to the volume of flow, equal portions of the collected samples should be deposited in a container to form the composite sample.

4. Samples of sewage should be composited in wide mouth containers.

Two methods of sampling sewage and sewage effluents which are not in general use are included in Appendices A and B: Appendix A, Pitcher Pumps for Sampling Sewage and Sewage Effluents. Appendix B, Automatic Sampling Machines.

Data concerning sampling at sewage treatment plants located in Connecticut, Rhode Island and Massachusetts are presented in Appendix C.

Data concerning sampling at sewage treatment plants located outside of the New England States are presented in Appendix D.

All of these data, together with information concerning laboratory examination of the various samples, has been furnished to the Committee by the many plant officials. Acknowledgment of our appreciation of this coöperation is hereby expressed.

Schedule of Sampling of Sewage and Sewage Effluents

The Committee recommends:

1. Chemical examination upon grab samples of sewage or sewage effluent should be eliminated. Dissolved oxygen determination and bacteriological examinations may and should be made upon grab samples. These samples should be collected with such frequency and regularity that the tabulated results will be representative of the condition of the sewage or sewage effluent during the period of sampling.

2. Chemical examinations, including biochemical oxygen demand of sewage and sewage effluent, should be made upon composite samples

and these composite samples should be collected in the following manner.

(*a*) *At the large sewage treatment plant where personnel is available.* The composite sample should be collected over a 24-hour period. The interval of sampling should not be greater than one hour and should be shorter whenever possible.

(*b*) *At all plants where the personnel is not available for 24-hour composite samples.* The composite sample should be collected over the working day and the interval of sampling should be ten or fifteen minutes. *Alternate method;* The composite sample should be collected over a period of a few hours, increasing the frequency of sampling whenever possible and rotating the hours of collection upon succeeding days.

(*c*) *Where samples are to be collected by a representative of the state or municipal bureau.* The composite sample should be collected over the working day and the interval of sampling should be as frequent as ten or fifteen minutes unless the conditions indicate the desirability of 24-hour sampling.

(*d*) *Comparable samples.* In (*b*) and (*c*), it is desirable that a reasonable period of lag should be provided for at the beginning and end of the sampling period to correspond roughly with the period of detention of the sewage in the treatment units.

(*e*) *At activated-sludge sewage treatment plants.* The sampling schedule according to (*d*) will generally cover a large part of a 24-hour period. The total period of time of sampling should provide for at least 6 hours of sampling for each treatment unit.

(*f*) *Special samples.* Exceptions to composite samples for chemical examination should be made only during such special experimental work when grab samples at stated intervals will furnish the required data. At plants where sufficient laboratory data concerning representative samples have been obtained, it may be possible to collect single grab samples of sewage and effluents, the analyses of which will approximate those of 24-hours composite samples.

(*g*) Published tables of analytical data should include a statement as to the method of collection of the samples. This statement may be included in the text of the publication or given as a footnote.

3. The practice of collecting composite samples of sewage and sewage effluent over a period greater than 24 hours should be discontinued. Samples which are so collected are not representative of the liquid from which they were taken owing to changes in character during the long period of collection.

4. Composite samples should be kept at a temperature between 1–8° C. (34–46° F.) until the laboratory examinations can be made.

5. From these composited and well mixed samples, smaller portions of each can be used for the required tests.

6. If weekly composite samples are made in the laboratory, these samples should be composited in proportion to the 24-hour flow, each day of the week, and properly preserved as provided for in the "Standard Methods for the Examination of Water and Sewage."

Sampling of Sludge

The local conditions pertaining to sludge disposal vary greatly from one plant to another. The importance of frequent sampling is not as great as with sewage. Therefore, the Committee recommends that sampling of sludge be done as frequently and regularly as seems desirable in the following instances.

1. Draining of settled sludge from settling tanks.
2. Determination of stage of digestion in sludge digestion tanks.
3. Drawing of digested sludge on to drying beds.
4. Any conditions in connection with the ultimate disposal of the sludge.

Sludge sampling should be so planned and executed that the laboratory examination of the sample will be representative of the sludge sampled. The proper sampling routine should be determined at each plant according to the existing local conditions and requirements.

APPENDIX A

Pitcher Pumps for Sampling Sewage and Sewage Effluents

At some sewage treatment plants located in Ohio, pitcher pumps have been permanently installed at the various sewage and effluent sampling stations. This Committee has not been able to experiment with such pumps for this purpose and has only the following comment to offer.

The pump inlet should be located only after sufficient investigation has been made to assure the collection of a representative sample. This matter might be one for investigation by a Committee of Plant Operators who are in a position to undertake systematic studies.

APPENDIX B

Automatic Sampling Machines

Automatic Sampling Machines.—No efficient sampling machine has been developed at a low enough cost to result in its extensive installation at sewage treatment plants. The successful sampling machine should be capable of collecting samples in proportion to the volume of flow or of placing each sample in a separate container for later compositing.

Failure to meet either of these requirements, mechanical defects, relatively high purchase price and a limited purchasing field have tended to

TABLE I

LOCAL COLLECTION AND EXAMINATION OF SAMPLES—CONNECTICUT

A—Municipal Plants

Municipality	Type of Plant	Samples	Suspended Solids	Oxygen Consumed	Biochemical Oxygen Demand	Residual Chlorine	Hydrogen Ion Concentration Sludge	Settleable Solids
Danbury	Settling tanks, digestion tank, sand filters	Weekly					x	
Greenwich (4 plants)	Septic and Imhoff tanks, chlorination	Grab samples				x		x
Litchfield	Sand filters, chlorination	Daily				x		
Manchester (So. Manchester)	Settling tanks, fine screens	Once every 2 weeks						
		3 times daily	x	x	x			x
New Canaan	Activated sludge, sand filters, chlorination	Daily				x		x
		Occasionally	x	x	x			
New Haven	Settling tanks, chlorination	Once each shift daily				x		x
New London	Septic tanks, chlorination	Grab samples				x		x
Norfolk	Septic tanks, sand filters	Grab samples						x
Norwalk	Settling tanks, digestion tanks, chlorination	Daily				x	x	x
Stamford	Imhoff tanks, chlorination	Grab samples				x		x
Stratford	Imhoff tanks, chlorination	Daily				x		x
Vernon (Rockville)	Fine screen, settling tanks, digestion tanks	Grab samples						x
Watertown	Imhoff tanks, trickling filters	Grab samples						x
West Haven (2 plants)	Septic tanks, Imhoff tanks, chlorination	Grab samples				x	x	

All samples are grab samples.

B—State Institutional Plants

State Institutions	Type of Plant	Samples	Suspended Solids	Oxygen Consumed	Biochemical Oxygen Demand	Settleable Solids	Residual Chlorine	Hydrogen-Ion Concentration Sludge
East Lyme (State Farm for Women)	Imhoff tank, sand filters	Grab samples						x
Groton (Mystic Oral School)	Septic tanks, sand filters, chlorination	Daily					x	
Mansfield (Conn. Agri. College)	Sedimentation tanks, digestion tank, sand filters	Grab samples				x		
Mansfield (State Training School)	Septic tanks, sand filters	Grab samples				x		
Middletown (Conn. State Hospital)	Imhoff tanks	Grab samples				x		
Newington (Cedarcrest Sana.)	Imhoff tank, laundry waste chemical precipitation tanks, sand filters	Grab samples				x		x
Norwich (State Hospital)	Settling and digestion tanks	Grab samples						x
Rocky Hill (Veterans' Home)	Imhoff tank	Grab samples				x		x
Shelton (Laurel Heights Sana.)	Imhoff tank chlorination	Daily					x	

All samples are grab samples.

discourage the design of automatic samplers for use at sewage treatment plants. The plant which would use one or more samplers of any considerable value generally is one which maintains 24-hour operator service. This condition must be given consideration in anticipating the design and ultimate cost of an automatic sampler.

The history of the use of automatic sampling devices at sewage treatment plants is quite brief.

Chicago, Ill.—The North and West Side plants are equipped with a number of automatic samplers which take a small sample of sewage or effluent about every two minutes and discharge it into a one-gallon bottle for a 24-hour composite sample. The particular objection to this type of sampler is that the size of the sample is constant regardless of the variation of the volume of flow.

Baltimore, Md.—Automatic samplers of two concerns have been tried in past years without success. At the present time, consideration is being given to an automatic sampler which is being developed by a New York City concern. It is claimed that this machine possesses the advantages of collecting the sample at any desired elevation in the flowing liquid and in proportion to the volume of flow by increasing or decreasing the frequency of sampling.*

Worcester, Mass.—For a number of years previous to the commencement of operation of the present plant in 1925, an automatic sampling machine was used for sand filter effluent at the former plant. Samples were collected hourly and were of a uniform size. During the winter months it was always necessary to abandon the use of the machine. It was constructed to use with comparatively shallow depth of liquid moving fairly slowly and for that reason has never been moved to the present plant.

APPENDIX C

Sampling at New England Sewage Treatment Plants

Sewage treatment in the New England states is practically confined to Connecticut, Rhode Island and Massachusetts. According to the data collected, sampling throughout 24 hours is carried out at only five plants; namely, Worcester, Fitchburg and Brockton, Massachusetts, and Woonsocket and Providence, Rhode Island. At the latter plant, hourly sampling to make a 24-hour composite sample is done only twice each month. At all other plants, sampling generally consists of grab samples at the convenience of the operator, either for one or more regular tests or to make composite samples for the State Department of Health.

Connecticut State Department of Health.—A large amount of the sewage sampling in this state is done by representatives of the Bureau of

* *Water Works and Sewerage*, September, 1932.

TABLE II

LOCAL COLLECTION AND EXAMINATION OF SAMPLES—RHODE ISLAND

Municipality	Type of Plant	Samples	Settleable Solids	Available Chlorine	Biochemical Oxygen Demand	Hydrogen-Ion Concentration	No. of Bacteria	*B. Coli*	Suspended Solids	Volatile Solids	Turbidity	Ammonia	Dissolved Oxygen
Pawtucket	Chlorination	Occasional Grab samples		x									
E. Providence	Settling tanks chlorination	Grab samples 8 A.M., 1 P.M., 4 P.M.		x									
Providence	Settling tanks chlorination	Grab samples twice daily; rotating hr. schedule			x	x							
		Every 3 hrs.		x				x					
Warren	Settling tanks chlorination	Grab samples, 8 A.M., 1 P.M., 4 P.M.		x									
Westerly	Imhoff tank	Grab samples once or twice weekly	x										
Woonsocket	Activated sludge sand filters	*Screened sewage	x		xx	xx	xx	xx	xx	xx	x	xx	**
		*Primary tank effluent	x		xx	xx	xx	xx	xx	xx	x	xx	
		*Final settling tank effluent	x		xx	xx	xx	xx	xx	xx	x	xx	**
Woonsocket		*Effluent sand filters	x		xx	xx	xx	xx	xx	xx	x	xx	**

* 24 hour composite sample; 50 cc. per m. g. d. rate, once an hour, using a dipper, with outdoor storage of sample bottle.

x—Daily. xx—Alternate days of the week. ** Occasional grab samples.

Settling tests to determine rapidity of settling of floc and note clarity of supernatant liquor—aeration tank effluent.

TABLE III

LOCAL COLLECTION OF SAMPLES—MASSACHUSETTS

| Massachusetts | Type of Plant | | |

Table IV

Examination of Samples—Massachusetts

Massachusetts	Sample Collection: Composite: Daily	Sample Collection: Composite: Weekly	Sample Collection: Composite: Monthly	Sample Collection: Grab: Once Weekly	Sample Collection: Grab: 2-3 Times Weekly	Sample Collection: Grab: Twice Monthly	Sample Collection: Grab: Each Tank Unit	Sample Collection: Grab: Each Filter Unit	Sample Collection: Grab: Each Main Drain	Sample Collection: Grab: Occasional	Samples Tested: Screened Sewage	Samples Tested: Primary Settling Tank Effluent	Samples Tested: Imhoff Tank Effluent	Samples Tested: Trickling Filter Effluent	Samples Tested: Final Settling Tank Effluent	Samples Tested: Sand Filtration Effluent	Samples Tested: Wet Sludge	Samples Tested: Air Dried Sludge	Analytical Determinations: Nitrogen: Free Ammonia	Analytical Determinations: Nitrogen: Albuminoid Ammonia	Analytical Determinations: Nitrogen: Organic	Analytical Determinations: Nitrogen: Nitrates	Analytical Determinations: Nitrogen: Nitrites	Analytical Determinations: Solids: Settleable	Analytical Determinations: Solids: Total	Analytical Determinations: Solids: Dissolved	Analytical Determinations: Solids: Suspended	Analytical Determinations: Solids: Volatile Matter	Analytical Determinations: Oxygen Consumed	Analytical Determinations: B. O. D.	Analytical Determinations: pH	Analytical Determinations: Chlorides	Analytical Determinations: Dissolved Oxygen	Analytical Determinations: Relative Stability	Analytical Determinations: Iron	Analytical Determinations: Specific Gravity	Analytical Determinations: Moisture, Per Cent	Analytical Determinations: Total Nitrogen	Analytical Determinations: Weight, Cubic Yard
														o	o																									
Worcester	x				o						x		x	x	x							o	o	x			x			x				o					
Brockton		x									x	x		x	x	x			x	x		x	x		x	x	x	x	x			x							
Fitchburg		x									x		x	x	x				x	x		x	x		x				x			x							
Worcester		x									x		x	x	x				x		x								x			x							
Worcester			x								x		x	x	x										x	x	x	x							x				
Brockton				x							x	x		x	x	x														x	x		x						
Brockton				x					o					x	x	o																		x					
Fitchburg				x											x																		x	x					
Worcester					x		o	o						o	o							x	x										x						
Brockton				o			x					x						x										x			x					x	x		
Brockton							x								x			x										x			x					x	x		
Fitchburg							x						x		x			x										x			x					x	x		
Worcester			o				x						x		x			x										o			x				o	x	x	*	
Brockton										x		x			x				x									x									x		x
Fitchburg										x			x		x				x																		x		x

* 1 in 3 to 5 samples.

TABLE V

COLLECTION OF SAMPLES—PLANTS LOCATED OUTSIDE OF NEW ENGLAND

City	Daily Sample: 24-Hour Composite	Daily Sample: Interval-Collection, Hours	Daily Sample: Method of Collection	Daily Sample: Proportional to Flow	Daily Sample: Storage: Uniform Quantity Cubic Centimeters	Daily Sample: Storage: Outside Insulated Box	Daily Sample: Storage: Outside Insulated Box Room Temperature Refrigerator	Weekly Composite Sample: Proportional, M. G. D.	Weekly Composite Sample: Preservative: Uniform Quantity Cubic Centimeters	Weekly Composite Sample: Preservative: Sulphuric Acid Formaldehyde Chloroform	Weekly Composite Sample: Storage: Room Temperature Refrigerator	Monthly Composite Sample: Preservative: Proportional Uniform Quantity Cubic Centimeters	Monthly Composite Sample: Preservative: Sulphuric Acid Formaldehyde	Monthly Composite Sample: Storage: Chloroform	Monthly Composite Sample: Storage: Room Temperature Refrigerator	Wet Sludge Sample: Composite Acc. Tank	Wet Sludge Sample: Composite Acc. Day	Wet Sludge Sample: Interval of Collection, Minutes	Wet Sludge Sample: Column of Sample Cubic Centimeters	
Akron, O.	*	1½	P. P.	*			*		250	* *	*	None				*		....	..	
Alliance, O.	*	1	D	*			*	*		* *	*	None				*	*	5	300	
Aurora, Ill.	*	2	*	N	n. s.		*	None				None				*	*	240	750	
Baltimore, Md.		None		*				None				Daily catch		*			*	10–15	..	
Canton, O.	*,	2	*	N	400		*	None				None				n. s.				N—sewage, Yes; effluents, No.
Chicago, Ill. (No.)	*	1/10	A	N	5	*		n. s.				n. s.				n. s.				
(W.)	*	1/20	A	N	5	*		n. s.				n. s.				n. s.				
(Cal.)	*	1	D	*			*	n. s.				n. s.				n. s.				
Cleveland, O. (So.)	*	2	*	*				n. s.		*		None					*	indef.	n. s.	Indef.—indefinite
(E.)	*	1	*	*				n. s.				None				n. s.				
(W.)	–	1	*	*				n. s.				None				n. s.				
Columbus, O.	*	2	*	N	300			None				50 cc. daily		*	*	no reg.		method		Reg.—regular
Dayton, O.	*	1	P. P.	*				n. s.			‡	None				*		n. s.	n. s.	
Decatur, Ill.	*	1	D	N	250		‡	400		*	‡	None				*		B-M-E	1000	‡ water - cooled boxes

Durham, N. C.	*	1	*	*			*	None			None		1 sample		500				
Elyria, O.	*	1	*	*		*		*	*	*	None		*	2	n. s.				
Fort Worth, Tex.	*	2	*	*			*	None			None		*	60	473				
Fostoria, O.	*	1	*	*		*		*	*	*	None		n. s.						
Grand Rapids, Mich.	*	1	*	N	250	*	‡	None			None		*	10	946	‡ Over Sunday			
Greensboro, N. C.	*	1	*	N	150	*		None			None		n. s.						
Madison-Chatham, N. J.	‡	1	*	n. s.			*	n. s.	*	*	None		n. s.			‡ 2 Days per week			
Marion, O.	*	1	*	*				*	*	*	None		n. s.						
Milwaukee, Wis.	*	1/2	*	*			* *	None			None		*	60	500				
Peoria, Ill.	*	1/2	*	N	60		*	None			None		* *	60	120				
Rochester, N. Y.	*	2	*	N	315	*		2 day Composite 1 test			n. s.	*	n. s. *	B-M-E	3784	B-M-E — Beginning-Middle-End			
Schenectady, N. Y.	*	1*	*	N	300	*		300	* *	*	None		n. s.			† 1 hour-days; twice, 900 cc. nights			
Trenton, N. J.	‡	1	*	Y			*	None			None		n. s.			‡ 2 days per week; thymol preservative			
Urbana, Ill.	*	1	*	Y			‡	None			None		n. s.			‡ water - cooled boxes			
Waco, Texas	*	2	*	Y		*		None			None		*	120	50				

* = Yes N = No n. s. = not stated P. P. = Pitcher Pump
* or D = Dipper

TABLE VI

EXAMINATION OF SAMPLES—PLANTS LOCATED OUTSIDE OF NEW ENGLAND

City	Sample Collection: Composite: Daily	Composite: Weekly	Composite: Monthly	Grab: Daily	Grab: 2-3 Times Weekly	Grab: 1 Time Weekly	Grab: Occasional	Samples Tested: Sewage: Raw	Sewage: Screened	Effluent: Primary Settling	Effluent: Imhoff Tank	Effluent: Aeration Tank	Effluent: Trickling Filter	Effluent: Final Settling	Nitrogen: Free Ammonia	Nitrogen: Albuminoid Ammonia	Nitrogen: Organic	Nitrogen: Nitrates	Nitrogen: Nitrites	Analytical Determinations: Solids: Settleable	Solids: Total	Solids: Dissolved	Solids: Suspended	Solids: Volatile	Oxygen Consumed	B. O. D.	pH	Chlorides	Dissolved Oxygen	Relative Stability	Iron	Alkalinity	Turbidity	Immediate Chlorine Demand	Number of Bacteria
Akron, O.	x							x			x	x	x							x			x	x		x	x							
Cleveland, O. (So.)	x							x			x	x	x								x		x			x	x							
	x							x					x												x			x		x	x			
	x											x	x				x	x																
Columbus, O.	x							x			x	x								x			x			x	x							
	x											x						x	x									x						
Dayton, O.	x							x			x									x	x	x	x			x							
Decatur, Ill.	x							x			x	x	x							x			x			x							
	x											x						x										x	x					
Elyria, O.	x							x			x		x										x			x		x	x		x	x		
	x												x																x					
Fostoria, O.	x							x		x		x	x							x						x			x		x			
	x							x																						x				
Marion, O.	x							x			x		x	x												x	x				x			
Rochester, N. Y.	x							x			x									x						x							
Grand Rapids, Mich.	x							x		x										x	x	x	x	x		x	x				x			

| | | |

Sanitary Engineering of the Department. Bacteriological Samples: grab samples taken in sterilized bottles. River Water and Sludge Samples: grab samples. Industrial Waste Liquor: grab samples. Where necessary, they are mixed to approximate the character of the total discharge into the stream.

Samples for Chemical Examination: Samples of sewage and effluents are collected at 10 to 15 minute intervals, using a dipper and pouring a portion into pails or cans. Contents of each pail or can is thoroughly mixed and a portion, always the same size, is dipped and poured into a 2400 cc. bottle containing 5 cc. of chloroform. A second portion of the same size is poured into a second bottle containing no preservative, from which the sample is taken for the biochemical oxygen demand test. The sampling period usually covers a range of at least 6 hours.

The practice of sampling sewage has not been confined to raw or to screened sewage, the ultimate treatment being a deciding factor. An arbitrary lag is usually made between collection of the first sewage and first effluent samples, although there is no definite certainty that this always indicates the actual conditions at the plant.

Rhode Island—Board of Purification of Waters.—Monthly samples of sewage and effluents for this Board are composited of daily grab samples of about 125 cc. collected by the operators of the municipal plants at Warren, East Providence and Westerly. These monthly samples are preserved with chloroform. The daily portions are generally collected during the forenoon.

Hourly samples for the 24-hour composite samples are collected once a month for the Board at Central Falls and Woonsocket and twice a month at Providence. Chloroform is used as a preservative. One-half of each composite sample is retained by the plant laboratory at Woonsocket and Providence.

At East Greenwich composite samples (7:00 A.M. to 4:00 P.M) are collected once a month for the Board by the plant operator.

Bacteriological, settleable solids and biochemical oxygen demand grab samples are collected twice a month at East Providence, Warren and Providence and once a month at the other treatment plants by agents of the Board.

Massachusetts—State Department of Public Health.—Samples are collected by the operators of all plants once each month for the State Department of Public Health. Chloroform is used as a preservative. At the smaller plants, there are usually catch samples collected according to the operator's convenience, although other directions may have been given by the assistant engineer of the Department. The samples from the Worcester, Fitchburg and Brockton plants, which maintain laboratory control, are portions of the daily composite samples. All sample collection

at the Lawrence experimental station laboratory of this Department is confined to the working day hours.

Data concerning local collection and examination of samples is presented in Tables I, II, III and IV. The amount of work which can be done is greatly governed by the financial resources, available time and the assistance given.

APPENDIX D

Sampling at Sewage Treatment Plants Outside of New England

Information concerning sampling of sewage and effluents at many plants located outside of the New England states is presented in Tables V and VI. This information has been furnished by the officials in charge of these plants and the Committee express its appreciation of their cooperation.

The data contained in these tables indicate:

1. All of the plants collect twenty-four hour composite samples.
2. At a majority of the plants, the interval of sampling into the composite sample is one hour.
3. With four exceptions, collection of the samples is done with a dipper or by dipping with a small bottle.
4. At approximately two-thirds of the plants, the collected portion deposited in the composite sample is in proportion to the volume of flow at the time of collecting.
5. At only one-fourth of the plants is a weekly composite sample prepared. One-half of this number prepare this sample in proportion to the daily flow.

Comments on Rudolfs' and Miles' Articles on "Heat Losses from Sludge Digestion Tanks"

By T. R. Haseltine

Superintendent, Salinas Sewage Treatment Plant

Although heated sludge digestion tanks have been in common use for several years there has been surprisingly little information published, on the subject of heat losses, of sufficient value to be of much assistance to the designer of heating systems for such tanks. In most of the publications tank and air temperatures are given, and a few give sewage temperatures, but few, if any, report ground temperatures, although most digestion tanks are surrounded by earth embankments and some have earth fill over their tops. It is common knowledge that average ground and air temperatures may differ greatly, particularly during the winter and summer months in the eastern climates. Early in 1931 Downes[1] pointed out that "ground temperatures are the governing factor in digestion temperatures if heat is not applied," but the work of Rudolfs and Miles constitutes the first scientific approach of the subject and should be of untold assistance to designing engineers. In their first paper[2] they developed, from laboratory experiments, the formula

$$\phi = \phi_1 e^{-kt}$$

where

ϕ = degrees difference (C.) between sludge and surrounding air at given time,
ϕ_1 = initial value of ϕ,
T = hours for cooling from ϕ to ϕ.

which expresses the rate of cooling of the sludge as a function of the initial temperature difference between it and its surroundings, the time of cooling, and "k," a constant that varies with size, shape and composition of the container. Before discussing their attempts[3] to apply this formula to field conditions the writer wishes to emphasize two conditions that applied to the laboratory experiments upon which the formula was based but which do not apply to ordinary field conditions.

1. In the laboratory the containers were filled with sludge at the outset and no sludge was added or withdrawn during the cooling time. In the field fresh solids are usually added to the tanks daily, thus displacing an equal volume of supernatant liquor of a higher temperature. Obviously, this constitutes a loss of heat that is dependent only upon the volume of the additions and the temperature difference between the incoming and outgoing liquids; it is independent of the temperature difference between the ground and the tank contents.

2. In the laboratory cooling took place in an environment of uniform temperature. This condition does not occur in the field. Although the

natural ground temperature remains practically constant for weeks at a time the authors found[2] that "there was a considerable variation (in the earth temperature) in the first 2 feet below the surface due to changing air temperatures." Digestion tank covers frequently consist of only 6 inches of concrete exposed to the air and seldom if ever are covers buried under as much as 2 feet of earth fill. In a cylindrical digestion tank having a depth equal to its radius the cover area amounts to 25 per cent of the total surface area and variations in air temperature certainly effect the heat losses through that portion of the tank surface at least.

In their second paper[3] the New Jersey investigators attempted to apply their formula to the field conditions existing at Freehold, N. J. They state as follows:

"On July 18, the heat was turned off and the digestion tank allowed to cool, the recording thermometer in the tank registering the rate of cooling of the sludge. *During this time regular additions of fresh solids were continued and the supernatant liquor displaced.*"

"The average daily temperatures of the cooling tank are plotted against time in Figure 5 and the logarithms of the temperature differences between the tank and the ground against time in Figure 6. Within the limits of accuracy of the instruments used, the theoretical curve, shown as a solid line in Figure 6, developed in the laboratory[2] in experiments on the rate of cooling of the sludge agrees closely with the actual data obtained in the field."

Although it is true that the data in their Figure 6 are in good agreement, a close inspection will show that of the 18 plotted temperature differences over the 21-day cooling period 12 do not fall on the theoretical curve. Figure 5 is on too small a scale to permit an accurate check of the field data, but a careful study of it shows that the variation on 7 of those 12 days might be accounted for by either, or both, a variation in the amount of fresh solids pumped to the digester or a variation in the mean air temperature. On at least 2 of the 6 days on which the actual and theoretical temperature differences agreed the amount of sludge pumped to the tank was below the average, thus tending to cause slower cooling, while the air temperatures were lower than the average, thus tending to cause more rapid cooling; the one tendency probably offset the other. It seems logical to believe that if the two variable factors of daily charges and air temperatures could have been eliminated an even closer agreement between actual and theoretical rates of cooling would have been obtained.

Rudolfs and Miles compute the value of "k" from the theoretical curve in their Figure 6 and find the rate of cooling to be 0.0391 degrees F. per day. From this rate, the average temperature differences between the tank contents and the ground during two previous periods of applying heat, and the volume of sludge in the tank, they compute the theoretical

heat losses to be 1,173,000 and 1,612,875 B. t. u. per day, respectively, for their first and second periods. They point to the close agreement with the *heat added*, 1,172,000 and 1,622,000 B. t. u. per day, respectively, during the two periods. In the writer's opinion the fact that any such agreement exists is a pure coincidence and is due to the fact that the daily average amounts of fresh solids pumped to the digestion tank were fairly equal during the two periods of applying heat and the cooling period. The Salinas experiences, described later, will serve to emphasize this point.

Upon inspecting Table I on page 26 of their second article one is struck by the fact that the heat losses during the first period were 140 per cent of those during the second period although the average temperature difference between the tank and the ground was only 40° F. during the first period as compared with 55° F. during the second period. Obviously such a condition is contrary to reason and contrary to the formula developed. In attempting to account for this discrepancy the original data in their Figure 5 was again found to be plotted on too small a scale to permit an accurate check. However, it appeared that the total volume of fresh solids added to the tank during the first period more nearly approached 264,000 gallons than it did 221,000 gallons as stated at the bottom of page 24. If such be the case then the heat used during the first period would be 990,000 B. t. u. per day instead of 828,000 B. t. u. and the heat lost would be 182,000 B. t. u. per day instead of 344,000 B. t. u. That is, the heat lost during the first period would be only 74 per cent of that lost during the second period, which appears to be a much more reasonable figure.

Since the amount of "heat used" depends entirely upon the amount of solids added to the digester and upon the difference in temperature between the digesting sludge and the fresh solids it is subject to as accurate an estimate by the designer as are digestion tank capacities or many other features of the design. In the writer's opinion the chief value of the formula developed by the New Jersey investigators lies in the fact that it offers the designer a means of computing the "heat losses" in advance, provided the value of "k" is known. The value of "k" for the Freehold tank may be computed as follows:

For Period 1

$$k = \frac{182{,}000}{12{,}000 \times 62.5 \times 40} = 0.00608$$

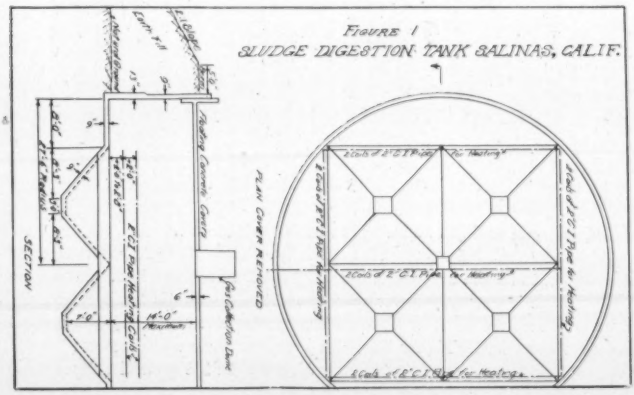
For Period 2

$$k = \frac{245{,}600}{12{,}000 \times 62.5 \times 55} = 0.00594$$

The values as found from the two periods appear to be in very close agree-

ment, in view of the doubt relative to the actual heat losses during the first period.

Rudolfs and Miles[3] observed "that during cold weather when air and ground temperature changed very little, the amount of heat required to maintain the temperature of the tank was less on sunny than on cloudy days." They attributed the relatively lower heat losses during Period 2, shown in their Table I and previously mentioned herein, to the fact that during that period "there was almost continually clear weather and the average air temperature was 8° F. higher than during the first period." It is doubtful if this could account for the large difference in heat losses shown in their Table I but it is quite possibly the explanation of the slightly higher value of "k" during the first period than during the second.



Salinas Experiences

As previously stated it is essential to know the value of "k" for different types of digestion tanks in order to realize the full value of the formula developed by Rudolfs and Miles. A search of the literature relative to heat losses from digestion tanks revealed that because most authors failed to report ground temperatures it was impossible to compute values of "k" from their data. In view of this fact it is thought that the results obtained at Salinas, California, may be of interest.

The Salinas digester has been previously described and illustrated in THIS JOURNAL;[4] Figure 1 will serve to illustrate its construction and insulation. Heating coils were placed in the digester when built; last winter the conventional type of gas fired boiler and circulating pump were

installed to heat its contents. All circulating water is metered and a recording thermometer is provided to keep a continuous record of the temperature of the water as it enters and leaves the boiler.

Fresh solids are drawn by gravity to a sump, from which they are pumped to the digestion tank. The volume of solids added each day is computed from the dimensions of this sump and the depth of sludge in it. The temperature of the sewage in the primary clarifier is determined daily at 8 A.M. and 4 P.M. The temperature of the fresh solids is assumed to be the same as the average of these two determinations.

At weekly intervals the digester is sampled at the 2-, 5-, 12- and 17-foot depths and samples analyzed for pH, solids and ash content. In taking the samples a thermometer is held in the discharge stream from the sampling pump and pumping is continued until the temperature remains constant. Samples are taken at points approximately midway between the center and walls of the tank.

At the same time that the digestion tank is sampled the average ground temperature is recorded. To obtain this we extended a 4-inch tile vertically downward into the ground a depth of 4 feet, at a point far removed from all structures. A thermometer, the bulb of which is submerged in a bottle of water, is kept at the bottom of this pipe except when pulled up to make temperature readings. The top of the pipe is plugged with a bunch of waste.

A maximum and minimum thermometer is exposed to outside air temperatures in a shaded spot and is read daily. The average air temperature is assumed to be the average of the daily maxima and minima. However, this average is probably lower than the actual mean air temperature for the periods herein considered, as shown by the fact that the ground temperature was slightly higher than this average. One would expect the air temperature to be equal to or slightly higher than the ground temperature during May and June in the Salinas climate.

The average results for two periods are given in Table I and the basic data for these periods are shown in Figure 2. The calculated values of "k" for the first and second periods are 0.0078 and 0.0095, respectively. It will be noted that there is nowhere nearly as close an agreement between these two values as there was for the two periods reported on at Freehold. This may be due to (*a*) more infrequent and less accurate determinations of tank temperatures, or (*b*) the variable volume of sludge in the tank during each period as a result of the utilization of the floating cover feature of the Salinas tank.

It will be noted that the chief difference between the two periods is in the average amounts of fresh solids added daily. These two periods were particularly selected to illustrate the importance of this factor. As previously noted "k" for the first period was about 82 per cent of its cal-

culated value for the second period; if the factor of amounts of daily additions of solids was neglected and the values of "k" computed on the basis of total heat added, as done by Rudolfs and Miles, the value for the

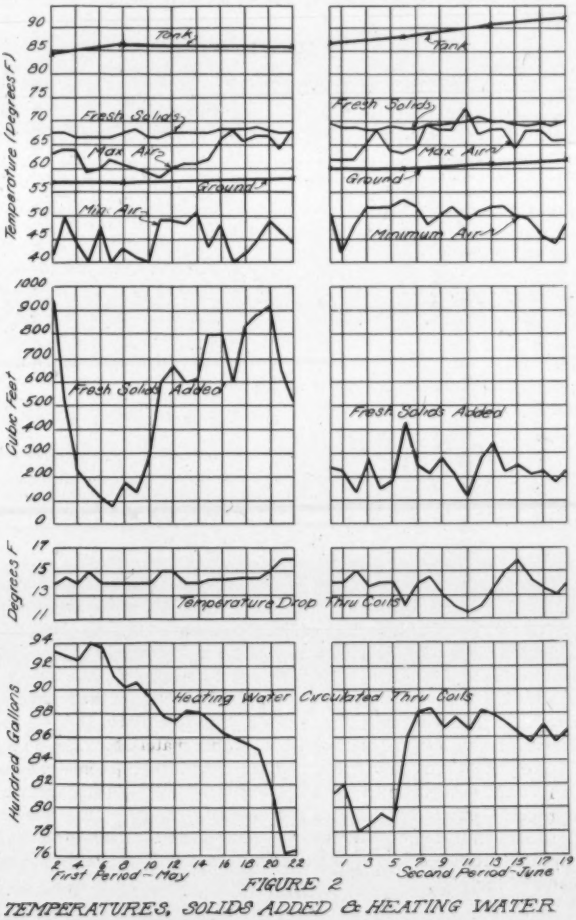


FIGURE 2

TEMPERATURES, SOLIDS ADDED & HEATING WATER

first period would be about 129 per cent of the value for the second period. This clearly illustrates the importance of considering the effect of the daily additions of fresh solids in calculating heat losses. The importance of this factor increases with the volume of solids added.

TABLE I

AVERAGE RESULTS AT SALINAS, CALIFORNIA

	Period 1	Period 2
Temperature of tank contents	85.8° F.	89.3° F.
Temperature of ground	57.3° F.	60.7° F.
Temperature of air	54 ° F.	58 ° F.
Temperature of fresh solids	67.7° F.	69.1° F.
Volume of heating water circ.	8730 G. p. d.	8380 G. p. d.
Temperature difference between incoming and outgoing water	14.5° F.	13.5° F.
Heat added daily	1,054,400 B. t. u.	942,000 B. t. u.
Volume of solids added daily	527 Cu. ft.	233 Cu. ft.
Temperature difference between fresh solids and tank contents	18.1° F.	20.2° F.
Heat used daily	596,250 B. t. u.	294,300 B. t. u.
Heat lost daily	458,150 B. t. u.	647,700 B. t. u.
Temperature difference between tank contents and ground	28.5° F.	28.6° F.
Volume of tank contents	33,050 Cu. ft.	37,200 Cu. ft.
Value of "k" computed on basis of heat lost	0.0078	0.0095
Value of "k" computed on basis of heat added	0.0179	0.0139

Before leaving the subject of Salinas experience brief mention will be made of the subject of heat transfer from coils to sludge. In this country galvanized wrought iron pipe has been quite generally used for coils; a few plants, here and abroad, have used copper or tinned copper pipe. There has been some question of the corrosion of the coils although most authorities believe that a coating of sludge forms around them that protects them from serious corrosion. Because cast iron has proved quite resistant to corrosion it was decided to use 2-inch cast iron pipe for the coils in the Salinas tank. The writer knows of no published data on the coefficient of heat transfer from cast iron pipe so used, therefore Table II is presented to show how cast iron compares with the other materials. There are approximately 600 linear feet of pipe from the recording thermometer through the tank and back again; all but 447.4 feet of the pipe, which makes up the coils proper, is encased in asbestos and covered with either tile or concrete, so it is assumed no heat is lost through that portion. The heating surface is computed from the length of the coils proper and the nominal internal diameter of the pipe.

TABLE II

HEAT TRANSFER OF METALS

Material	Length of Service	Average Coil Temperature, Degrees F.	Coefficient of Heat Transfer B. t. u. per Sq. Ft. per Hour per Degree F. of Temperature Difference	Authority and Reference
Copper	More than 1 year	?	10.2–11.1	Heilman and Müller 5
Copper	More than 2.5 years	122–140	10.2–12.3	Heilman 6
Tinned copper	Less than 1 year	176	3.06	Heilman 6
Galvanized wrought iron	15 months	103	10.7	Keefer 7
Ditto ?	(General average conditions)		30.0	Kivell 8
Black iron	2 months	95–106	7.6– 9.1	Downes 1
Cast iron	First 10 days	86	12.7	Salinas
Cast iron	2.5 months	109	8.1	Salinas
Cast iron	4.0 months	111	7.7	Salinas

Temperature Variations Within Digestion Tanks

Rudolfs and Miles[3] found two distinct layers of different temperatures within the Freehold tank, the temperatures within the layers being practically constant both horizontally and vertically. "The difference in temperature between the layers averaged about 10° F. during both periods of applying heat, the hotter layer being toward the bottom. The temperature variation apparently occurred at the supernatant-sludge interface and was not related to any particular position in the tank." Downes[1] "observed that with from 7 to 10 feet of sludge in the bottom of a digestion tank 20 feet deep, the sludge could be maintained at a temperature of 72° F. while the supernatant liquid above was at 60°. The transition from the higher to the lower temperature took place within a 6-inch boundary zone at the sludge surface." Fischer[9] gives a typical tabulation of conditions within the Salem, Ohio, digester that shows temperatures of 78° F. 5 feet down or 1.5 feet above the sludge line, 82° F. 1.5 feet below the sludge line and 83° F. 2 feet above the bottom of the tank, which was 20 feet deep.

On the other hand Keefer[7] reports that at Baltimore "provision was made for getting temperatures by means of a recording thermometer at two points in the tank, the first 5.5 feet and the second 17 feet below the roof. The upper thermometer was generally always in the sludge liquor zone, and the lower is in the sludge. During the 15 months' period that the tank has been in service the average temperatures at the two points in the tank have been practically the same. There have been times, however, usually of short duration, when the temperature at one point was as much as 5 or 6 degrees higher than the other." During the 4 months the heat-

ing system has been in service at Salinas there has never been more than 2° F. temperature difference between any two sampling depths and the bottom samples have been colder than the top ones just as often as they have been warmer.

Just why some tanks, or sludge, show temperature stratification and others do not is a problem difficult of solution. Rudolfs and Miles[3] suggest as possible explanations of such stratification (1) that the sludge absorbs and retains heat as suggested by Downes,[1] and (2) that heat is produced by the decomposition processes. In this connection it is interesting to note that Keefer and Kratz[10] found that Baltimore sludge, which shows no temperature stratification, usually evolved heat at the start of digestion but that this condition was soon followed by heat absorption. On the whole more heat was absorbed than was given off.

Whatever the cause of temperature stratification, it is evident that the phenomenon plays an important role in determining the heat losses from digestion tanks, since the tops of such tanks are generally more poorly insulated than the sides and bottoms. Thus at Freehold[3] the average temperature differences between the upper layer of liquor in the tank and the air were 21° and 35°, respectively, during the first and second periods of heating, while the corresponding temperature differences between the lower layer and the ground were 40° and 55° F.; the average value of "k" was 0.0060. At Salinas, where no temperature stratification occurred and the temperature differences between the sludge and the air were practically the same as those between the sludge and the ground, the average value of "k" was 0.0086. The higher value of "k" for the Salinas tank is probably due to (1) lower air temperatures in comparison with ground temperatures, (2) the absence of temperature stratification and (3) poorer cover insulation.

Since, with present knowledge at least, the designer cannot foresee whether or not temperature stratification will occur and since air temperatures will be lower than ground temperatures during the winter, when the heat losses will be greatest, a higher value of "k" should be assumed than either of the above values. Data similar to that collected at the Freehold and Salinas plants should be collected from several different types of tanks during the winter months in order to determine the proper range in value of "k" and to so make the formula of the New Jersey investigators of the greatest usefulness.

Position of Heating Coils

Rudolfs and Miles[3] state as follows:

"Locating the heating coils on the bottom of the tank, as practiced in some instances, would not appear best, since a mass of material which has already undergone active decomposition is kept at the optimum tempera-

ture for digestion. Locating the coils in the supernatant liquor would apparently make for greater heat losses. It is obvious therefore that heating coils should be located in the zone of most active decomposition, which under ordinary operating conditions would be from one-third to one-half way from the bottom of the tank. It is also probable that the digested sludge would sink to the bottom and be less disturbed by convection currents, with the result of greater compacting."

An inspection of Figure 1 shows that at Salinas the coils are located approximately in that position. It may therefore be of interest to record the following facts relative to the Salinas tank: (1) The temperature of the sludge at the 17-foot depth has always been practically the same as that at the 12-foot depth and therefore no heat is saved by raising the coils above the bottom of the tank. (2) There has never been much increase in solids concentration with depth. Before heat was applied the sludge at the 17-foot depth averaged 0.5 per cent more solids than that at the 12-foot depth. After applying heat it has averaged about 0.3 per cent more solids. If this decrease in concentration is due to convection currents it appears that if the coils were nearer the bottom the decrease in solids concentration might be serious.

Opinion differs as to the proper location of heating coils. Heilman[6] states as follows: "The coils may be placed on the bottom, as in Halle around the vertical walls or suspended in the upper part of the digestion room. This last type has the advantage of being removable for frequent cleaning so that the sludge crust which forms on the heating surface can be scraped off. The disadvantage is that its location in the upper part of the tank leaves the lower part of the tank cold and circulation of the sludge is required so as to bring the cold bottom sludge in contact with the heating coils.... The heating coils on the vertical walls are more advantageous, but horizontal stirring is necessary for the distribution of heat. No mechanical circulation is necessary when the coils are placed on the bottom. The warm sludge rises to the top, loses its gas and sinks to the bottom. In this way the entire contents of the digestion room are heated. The disadvantage of this system is that there is no distinct separation between sludge and liquor. Although the coils are inaccessible unless the tank is completely emptied, experience at Halle has shown that cleaning or repairing is very seldom necessary." Rudolfs and Miles found very little horizontal variation in temperature at Freehold but it is noteworthy that the tank was equipped with a stirring mechanism. It would be interesting to know whether or not stirring was necessary to secure the good horizontal distribution of heat observed there.

Some eastern plants have reported[11] trouble with cold scum collecting immediately under the tank covers during the winter. Under such conditions it might be desirable to apply part or all of the heat to the top of the

tank even though this might increase heat losses. In the writer's opinion it might be well to provide two, or even three, sets of coils at different elevations with cross connections so that any combination of the sets could be used as conditions demanded. Until definite data are available to show that mechanical stirring is not necessary for horizontal heat distribution it would be desirable to place the coils about midway between the center and the sides of the tank or to carry them across the center of the tank as done at Salinas.

Conclusion

In closing, the writer wishes to repeat that the work of Rudolfs and Miles on heat losses is a very important, and almost the first, step toward the scientific design of heating systems and the development of satisfactory tank insulations. The writer's comments have been made not to criticize that work but in the hope that they would assist in the understanding and use of the facts and formulas developed by the New Jersey investigators. To make their work most valuable it is necessary to determine the value of "k" for various types of tank construction and under varying climatic conditions. The writer has attempted to do this at the Salinas plant with only very mediocre success. As an apology for presenting data in such poor agreement it is desired to point out that the heating system at Salinas has been in use only four months, during which time there have been several varying conditions that made it more difficult to select comparable periods over which to collect the basic data. The desire to present these comments while the work of Rudolfs and Miles is still fresh in the minds of the readers and to make public the comparatively simple procedure followed at Salinas in collecting the data for calculating "k" in order that other plant operators may adopt or improve upon it has led to the perhaps premature publication of Salinas results.

References

[1] John R. Downes, "Gas Collection and Sludge Heating," THIS JOURNAL, **4,** 72 (Jan., 1932).

[2] Willem Rudolfs and H. J. Miles, "Heat Losses from Sludge Digestion Tanks," *Civil Engineering*, **2,** 481 (Aug., 1932); abstract, THIS JOURNAL, **4,** 918 (Sept., 1932).

[3] Willem Rudolfs and H. J. Miles, "Heat Losses from Sludge Digestion Tanks, II, Field Observations at Freehold, New Jersey," THIS JOURNAL, **5,** 17 (Jan., 1933).

[4] T. R. Haseltine, "Digestion of Activated and Primary Sludge at Salinas, California," THIS JOURNAL, **3,** 599 (Oct., 1931).

[5] Heilman and W. Müller, "Copper Heating Coils in Sludge Digestion Tanks," *Gesundheits-Ingenieur*, **54,** 533 (1931); abstract, THIS JOURNAL, **3,** 741 (Oct., 1931).

[6] Heilman, "Experiences with Artificial Heating of Digestion Tanks in the Treatment Plant of the City of Halle," *Gesundheits-Ingenieur*, **55,** 463 (1932); abstract, THIS JOURNAL, **5,** 179 (Jan., 1933).

[7] C. E. Keefer, "Large Scale Sludge Digestion Experiments at Baltimore," *Water Works & Sewerage*, **80,** 81 (March, 1933).

[9] Wayne A. Kivell, "Trend of Developments in Separate Sludge Digestion," THIS JOURNAL, **3**, 54 (Jan., 1931).

[9] Anthony J. Fischer, "Activated Sludge Digestion at Salem, Ohio," *Ibid.*, **3**, 54 (Jan., 1931).

[10] C. E. Keefer and Herman Kratz, Jr., "The Interchange of Heat During Sludge Digestion," *Loc. Cit.*, **5**, 3 (Jan., 1933).

[11] H. W. Taylor, "Operating Experiences with Separate Sludge Digestion," *Municipal Sanitation*, **3**, 413 (Oct., 1932).

Notes on Haseltine's Comments

BY WILLEM RUDOLFS AND H. J. MILES

Mr. Haseltine's comments on our papers on "Heat Losses from Sludge Digestion Tanks" are appreciated; as the question of proper design, insulation and heating equipment should be investigated further, and it gives us also an opportunity to emphasize briefly some points which might have been overlooked.

The formula developed in our papers was not intended to be used in its present form for design purposes, because the conditions in the field are not the same as in the laboratory, but it was the first step in developing a practical design formula. It was applied in the Freehold experiments to find its defects and possibilities. As a matter of fact there are more factors than the two differential conditions between laboratory and field experiments cited by Haseltine. The factors: (1) additions of fresh solids, and (2) variation in environment affecting cooling, are perhaps the most important "gross" factors, but even those are made up of several others. For instance, to take the apparent simple one of displacing an equal volume of supernatant liquid with fresh solids, Haseltine says: "Obviously this constitutes a loss of heat dependent only upon the volume of the additions and the temperature difference between the incoming and outgoing liquids." This is true, provided the specific heat of the sludge is the same as that of the sludge liquid. Some experiments made by the junior author indicate that the specific heat of the fresh solids and activated sludge is considerably less than that of water. The use of "1" as the specific heat of sludge gives an additional factor of safety.

A final formula should include a number of factors dealing with: Heat added to the tank in B. t. u. per day; average temperatures of the material in the tank, of the fresh solids added, ground and air; weight and specific heat of the fresh solids added daily; thickness and conductance of material used for insulation, area of tank surrounded by ground and air; rate of cooling of portion of tank surrounded by ground and air; heat absorbed or produced by the digestion processes; wind and sunlight, and possibly others. Modifications of some of the factors mentioned would be needed.

Sufficient information along these lines would make it possible to arrive at a definite final formula.

Our heat penetration experiments at Freehold show that the temperature of the embankment was considerably above the normal ground temperature, and that the heat travels through it in a horizontal direction. Therefore, the portion of the tank surrounded by the embankment is really subject to the air temperature. It may be possible that K_G (ground) and K_A (air) have the same value, but it would seem unwise to assume this at present.

Upon examining the original large drawing from which Figure 6 was made it is found that with two exceptions all points either fall on the theoretical curve or have a maximum variation of 1° F. When it is remembered that the smallest graduation on the charts of the self-recording thermometers used was 2° F., the variation from the theoretical curve was well within experimental error.

The statement was made in our second article of this series that the amount of heat required to maintain the temperature of the tank on sunny days was considerably less than on cloudy days. Since the temperature of the embankment is affected by the air temperature and also absorbs considerable heat directly from the sun we believe that the importance of this factor is greatly under-estimated. On sunny days the surface of the embankment often becomes considerably warmer than the air temperature (a fact well known by soil scientists), and by actual measurement may be higher than the temperature of the tank contents. Under these conditions the heat can leave the tank only through the bottom or through the portion of the tank walls above the ground surface.

The fact that Haseltine thus far has not found heat stratification in his tanks and only small differences in sludge density may be due to two conditions: (1) digestion time and (2) mixture of activated-sludge and fresh solids. With an increase in digestion time the separation of solids from the liquid increase, and supernatant liquid and sludge are more clearly separated. The sludge density is determined by the initial sludge concentration and the time of storage. The longer the digestion schedule the more chance has the older sludge to compact, with the result that the thickest sludge is nearest the bottom. By adhering to a strict digestion schedule, just sufficient to produce ripe sludge for drawing, the sludge will be more uniform and the sludge liquor becomes more dense.

It is well known that mixtures of fresh solids and activated-sludge take longer to show separation and that the sludge concentration is more uniform through the depth of the tank than when fresh solids alone are handled. It is also possible that the small differences in sludge concentration observed at Salinas were due to the fact that digestion processes were not as yet stable during the whole period. We have a case on record

where it took about a year before rapid separation of sludge and liquid took place continuously in a heated tank receiving mixtures of activated-sludge and fresh solids.

Horizontal variations in temperature were small at Freehold. The tank is equipped with a slow stirring mechanism. Laboratory experiments have shown that cooling of the center part of the containers is slower without stirring, that uniform heat distribution is better with slow stirring, so that it may be presumed that stirring in the tanks has some effect on the good horizontal distribution of heat observed at Freehold.

As stated above the experiments are continued, among which are efforts to separate heat of production, heat of absorption and specific heat of sludge and liquids continuously with the help of rather complicated and delicate apparatus. If more information is obtained in different parts of the country under varying conditions and materials, proper design formula may be eventually found.

The Pumping of Sewage and Sludge*

BY CHARLES E. GREENE

With Metcalf and Eddy, Statler Bldg., Boston, Mass.

In any given problem the volume of sewage is usually so great that the cost of pumping is the criterion in the selection of the method of pumping rather than convenience or other considerations.

Centrifugal pumps of a type which are reasonably free from clogging have been developed to such a point of pumping efficiency that the use of that type of pump has come to be general on new work.

The ideal method is to have the pumping rate follow the variations in rate of flow of the sewage to the pumping station. This method involves the least lifting of the sewage and produces a more uniform flow of sewage through the treatment plant.

In a normal day flows may vary from 50 to 175 per cent of the 24-hour average. The variation between days of low flow and days of high flow increases the range to be provided for to at least 200 per cent without allowance for leakage from high ground water, storm water or growth of the community contributary to the system. Allowances for these factors usually increases the maximum rate of pumping to 250 or 300 per cent of the normal dry weather flow.

At any one speed, a non-clogging centrifugal pump can handle such a limited range with acceptable efficiency and small variation in head that it is necessary to accept an undesirable inefficiency at certain constantly recurring pumping conditions if a fixed speed and only one pump is used. This situation forces the designer to use a variable speed pump, or several pumps which will cover the desired range, or to resort to intermittent pumping, using a pumping rate that is safely greater than the desired maximum rate of pumping. Speed variation over the necessary range leads eventually to inefficiency in the power units and involves some variation in suction-well level to effect the necessary control.

Intermittent pumping involves storage of the sewage between pumping periods. Storage involves a considerable variation in suction-well levels with additional lifting of the sewage as the result.

The first cost of providing storage at the necessary levels is usually so great that storage is limited by economical considerations to a small fraction of the average daily flow, seldom exceeding 5 per cent.

Larger sewage pumps give less trouble from clogging, and are more efficient. The usual practice, therefore, is to install larger pumps than those needed for the peak flow and operate them intermittently

* *Presented at the Spring Meeting of the New England Sewage Works Association, Woonsocket, R. I., May 1, 1933.*

with such storage as can be introduced without a great addition to the space required by racks and the pump well. This change in storage-well levels tends to make the system self-governing. With a high suction-well level, the head on the pump is low and the pump will deliver more sewage. As the pump drains down the suction well, the head increases and thus reduces the capacity of the pump.

A non-clogging centrifugal pump will usually come down to half its maximum capacity under the design conditions without its efficiency dropping below 60 per cent and with a 10 per cent variation in total head. This means that two pumps, one of about half the capacity of the other, will cover the range required by normal dry weather flow if the storage capacity, however small in volume, permits a difference in pumping heads of 10 per cent of the total pumping head. A close prediction of the total pumping head is essential to proper selection of the pumps for even passable operation.

When there is more than one pump, the lowest pumping costs will usually result from using regularly the smallest pump or smallest total pumping capacity that will carry through the daily peak by continuous pumping. For lower flows the next smaller combination should be used which will carry through the period of minimum flow without too much starting and stopping. The limiting condition may be fixed at not more than four starts per hour. A designer will seldom encounter a combination of conditions that requires more frequent starting than once an hour, except with very small units.

There are two limitations to the successful application of the non-clogging type of centrifugal pumps to the pumping of sewage: (1) the conditions where the rate of pumping must be less than about 400 g. p. m., and (2) conditions where the head exceeds 100 feet.

The first named limitation comes from the experience that the smaller pumps cannot handle successfully the clogging materials commonly present in domestic sewage. For these low flows pneumatic ejectors are a good solution. The second limitation arises from the practical undesirability of operating non-clogging type of centrifugal pumps at higher speeds than 900 r. p. m. Some of the better manufacturers of these pumps have set the limiting head as low as 80 feet. The author has seen this type of pump operate successfully at 1750 r. p. m. and against 120 ft. head.

The earmarks of a good non-clogging pump are a two-bladed impeller, a heavy shaft with heavy supports and rigid bearings, some form of support near the impeller, an end suction inlet and a simple casing. We usually set the limit for minimum clear way through the impeller at 2.5 inches, corresponding to a 4-inch pump. Many pumps with 6-inch connections are really 4-inch pumps so far as the internal dimensions around the impeller are concerned and as such will only pass a 2.5 inch spherical object.

It has been the writer's experience that a two-bladed impeller will give much less clogging trouble and can be run at higher speeds than a single bladed impeller or a three or a four bladed impeller. The higher speed makes for low first cost and the other factors reduce the inspection and maintenance enough to show up favorably on the operating costs.

Some sort of bar racks seem to be worth while ahead of most pumps. Good practice shows a spacing of 2 inches for the smallest pumps increasing to larger spacing as the pump size increases, until the racks are sometimes omitted entirely ahead of very large pumps. Racks with 2.5-inch clear opening rarely involve any arduous or objectionable cleaning, especially if there is a generous amount of total area through them. Screens, on the other hand, are a continual source of trouble. A pump that won't operate without a screen ahead of it ought not to be used for sewage.

The end suction inlet construction is essential to the clog-free operation of the pump and usually contributes to the accessibility and ease of inspection of the impeller. With the end suction, the impeller is usually overhung and consequently the size of shaft, rigid heavy bearings and the provision of some means of support near the back of the impeller become important.

Sewage pumps in operation or standing ready for operation need two things, lubrication and fresh, clean water. For lubrication, grease is better than oil for small and medium size pumps, especially where the pumps work automatically or are unattended. There is less waste of grease than oil. The leakage of oil from idle bearings and feed pipes, and the oil thrown from revolving shafts collect dirt and create undesirable conditions that increase the expense. When the bearings are above a certain size, or load or speed, or are operated for long periods continuously, nothing is quite so dependable as oil. We might place these critical points at 4-inch dia., 25 hp. and 1200 r. p. m. and one hour's operation, respectively.

The increasing use of ball bearings favors the use of grease for lubrication.

The fresh clean water is needed to seal and wash out the packing glands and to cause a flow through the close-fitting clearance spaces into the sewage to wash out the grit and other substances that would otherwise be carried into these spaces by the sewage. Some means should be provided to get this water supply without a direct cross connection between water and sewage, and without waste of water and danger of freezing.

Grease is sometimes used instead of water to seal packing glands, but I have never been completely satisfied as to the effect on the shafts or shaft coverings of the combination of grease, packing and corroded metal. Most pumping stations need and have water supply for several other purposes and the use of it on the pumps does not present any added problem except that of avoiding the cross-connection.

The use of centrifugal pumps is bound to involve the use of check valves. The clogging of these check valves and their tendency to induce water hammer make it necessary to use care in their selection and in the piping details. Horizontal check valves seldom clog badly and can be cleaned more easily than vertical check valves, which always clog badly.

With larger pumps, say above 10 inches, simple check valves become cumbersome and wasteful of power, and power operated pivot valves or cone-valves are used. Their control has to be carefully interlocked with the control of the pumping motors or power units.

Vertical pumps placed so as to be self-priming, at least when they start to pump, driven by motors far enough above them to have a dry and accessible location or a so-called "place in the sun" are developing enough advantages and no corresponding disadvantages in comparison with horizontal pumps to make them decidedly preferable. The advantages usually offset the higher first cost of the pumps and motors. The saving in building space alone is usually enough to swing the balance in their favor.

However, horizontal sewage pumps are being operated with automatic vacuum priming so successfully that we do not hesitate to use this combination when the conditions make the construction of a deep enough and large enough dry well undesirable. The Allentown sewage pumping station is an illustration. These pumps have a suction lift of 10 ft. to 15 ft., automatic vacuum priming, start and stop automatically from floats and have never failed to operate since the station was put into operation in 1929. This type of station is more pleasant for operators, and more impressive to the public. The machinery usually gets better attention than the type using vertical pumps located so as to be self-priming. Most of us will choose to take more risks and face more problems provided we can work in comfortable and clean surroundings, rather than to work in close, dark quarters, and on several floor levels. It must be admitted that horizontal pumps can be worked on more easily and under cleaner conditions than vertical pumps. Horizontal pumps permit a greater variety of driving units. Horizontal pumps should not be placed where a break can flood the pumps and motors. This is a point that is often overlooked. If the ground water conditions and their effect on the cost of construction do not decide the point perhaps the best criterion is whether or not the conditions are such that the continuous presence of operators is required. If operators are to be continually in attendance, a selection of horizontal pumps usually gives the most satisfactory results. If the station is to be unattended, vertical pumps are indicated.

The pumping of sludge, so far as we are interested in it, is merely the pumping of thick sewage with all the troublesome features of pumping ordinary sewage intensified. There are sometimes the added requirements

of handling the sludge gently so as not to break up the "floc," and of being able to know the rate of pumping and varying it quite accurately. In most cases the volume to be handled, or the concentration of the sludge, throws the pumping into one or both of the classes mentioned above as being exceptions to the usual practice of using centrifugal pumps. Where centrifugal pumps can be used, there is nothing better. The ease of varying the rate more than offsets the inability to use the pump as a meter of the volume pumped. There is little evidence that centrifugal pumps break up the "floc" more than other types of pumps.

The considerations already stated for use of these pumps on sewage apply also to their use for sludge, except that neither racks nor screens need be used and pumping efficiency is usually given less consideration than convenience and control.

Where the sludge volumes are small, reciprocating pumps of slow speed and small capacity are commonly used. The reciprocating pumps used for sludge are usually contractors unwatering pumps or "mud-hogs" with minor changes to make them more suitable to sludge pumping and to correspond with putting them in a stationary location.

If we accept the single cylinder or two-cylinder "mud-hog" as the best starting point for developing a sludge pump, my impression of the value of the various changes that I have seen tried out on them are as follows:

(1) When applying a motor drive have some slip in the drive either with V belts or short belt and idler, or a non-rigid mounting of the motor. Considering the location of most of these pumps probably the V-belt will last longer.

(2) Avoid a solid hook-up even if shear pins are depended on to prevent breakage of gearing. Shear pins are an uncertain protection to the machinery and a great provocation to the operator.

(3) Use ample air chambers on both suction and discharge piping at the pump.

(4) Install a by-pass, preferably directly from the pump discharge, to the pump suction. This allows easy starting, makes speed changing less abrupt.

(5) Ball valves although noisy have less slip, less plugging and are more easily renewable than any of the substitutes I have seen.

(6) For changing the rate of pumping, the throw or eccentricity of the crank can be varied by several good methods and a two-speed motor will give double the range of capacity.

(7) Use pistons instead of diaphragms especially if the pipe lines are long or if there is a suction lift.

(8) A pump with a 4-inch stroke and one or two 10-inch diameter pistons can run smoothly at 40 r. p. m. of the crank, but gets to be a battering ram when the stroke or speed is increased.

(9) A 6-inch column of sludge 100 ft. long, moving even at the low velocities common in sludge piping, is quite an impressive projectile when it meets a solid piston traveling in the opposite direction more than 40 times per minute. The effect is even worse with diaphragms.

(10) The disadvantages of diaphragm pumps are so obvious to those who have watched them perform that some other means of pumping sludge is being continually tried out.

Compressed air is used in various ways to handle sludge. One typical means is the pot-type ejector located to fill by gravity and connected to an air compressor for ejecting the sludge. These are as satisfactory for sludge as they are for sewage. Another means is to lift the sludge with air lifts vertically to open troughs high enough to have the sludge flow by gravity to the desired location. Compressed air should be avoided for pumping from closed tanks or into closed tanks because of the possibility of getting an explosive mixture of air with the gas that may be over the sludge in a closed tank. The hazards attending the presence of this gas become serious when it gets mixed with air, and particularly if air is drawn into or forced into a confined space when this gas is present. Even the atmosphere over a sludge drying bed covered with a glass enclosure may be dangerous at times. The use of compressed air should be carefully considered from this point of view.

Sewage Treatment at Jamestown, N. Y.*

BY L. A. BERGMAN

Director of Public Works, Jamestown, N. Y.

Jamestown has a population of something over 45,000 and has a separate system of sewage collection, the storm water being discharged into the Chadakoin River, which traverses the town, while the domestic sewage is collected in a sanitary system and is discharged through a 30-inch brick outfall sewer.

The Jamestown sewage treatment plant is located in the town of Poland, about $2^1/_2$ miles east of the city. The treatment plant was designed by H. Burdett Cleveland. It was put in service December 1, 1927, and has been operating satisfactorily since that time.

The character of the sewage is largely residential, very little industrial or trade waste reaching the system and causing no problems in connection with sedimentation or sterilization of the effluent from the Imhoff tanks.

The sanitary system suffers a great amount of infiltration but this has been alleviated as much as possible. A considerable portion of the main trunk sewer lies below the bed of the Chadakoin River and, due to faulty design and the construction methods of thirty-five years ago, many of the tiles were very badly cracked. Much of this was remedied by the reconstruction of 3237 feet of 24-inch sewer during 1931–32 as a work relief project. Other repairs to the collection system and the use of asphaltic sewer joint compounds, together with the discontinuance of about one-half of our flush tanks, have very materially lessened the load at the plant. The normal flow is about 3.1 million gallons per day, which is doubled at times of prolonged rains or spring thaws.

The raw sewage enters the plant from the 30-inch trunk sewer through a distributing chamber where the flow is regulated by means of baffles. These are intended to secure the same character of sewage in each of the three identical units between the distributing manhole and the chlorinating chamber. This has been quite difficult to accomplish because the right-angle turn in the direction of flow on leaving the trunk sewer gives a swirling motion to the sewage. This distribution chamber is provided with valves, one for each unit of the plant, so that flow can be cut off from any unit for cleaning or repairs.

Each unit is provided with a bar screen 10 feet wide with $^3/_4$-inch spacing. The amount of screenings per day is about 1250 pounds. The screenings are removed from the bars with hand rakes and conveyed in wheelbarrows to the dump, where they are covered with grit and earth as soon as possible. This hand work is at times very laborious and it is the intention to mecha-

* *Presented at the Spring Meeting of the New York State Sewage Works Association, Rochester, N. Y., June 9–10, 1933.*

nize this operation as soon as funds become available. Moreover, due to the difference in water level on the two sides of the screen and the resulting high velocity of the water, much material that should be screened out passes to the tanks. For the convenience of the operator a float and alarm device has been installed as a warning of any unusual clogging of the screens.

After leaving the screens the sewage enters the grit chambers, about 3 ft. by 20 ft. in size, where all the heavier grits are deposited. As originally designed, each grit chamber drained into a leaching basin, which became ineffective due to the nature of the soil. The method of cleaning was to shut off the unit and drain the grit chamber into the leaching basin and then remove the grit by hand. This proved to be a rather difficult operation. Subsequently, all three of the leaching basins were connected by a tile drain to an auxiliary sand filter bed, 4 ft. by 60 ft. in size and having a tile underdrain. This makes it possible to flush all of the grit by gravity directly to the filter bed where it is removed in a dry state and used for covering screenings. The labor of grit removal is thereby materially reduced. Ordinarily grit is removed about once a week and totals about 200 tons per year.

From the grit chambers the sewage enters the Imhoff tanks, each of which is 46 ft. by 72 ft. and 26 ft. deep, with a capacity of about 60,000 cubic ft. This gives a detention of about two hours for sedimentation, based on a flow of 5,000,000 gallons a day. Very little difficulty has been experienced in the operation of the Imhoff tanks but during the late summer season some foaming has occurred at infrequent intervals which has been overcome by the addition of lime and by agitation produced by dosing with fresh water under pressure.

The direction of flow through the tanks is reversed weekly, to secure a uniform deposit of sludge in the digestion chamber. The accumulation of sewage in the sedimentation chamber, causing the slot to become obstructed, is overcome by the use of a squeegee and chain. Settlement in the tanks is very satisfactory, as is indicated by the cone tests taken daily at 11 A.M., which is the time of peak load on the plant. These tests show 5 to 8 cc. per liter of solids in the influent while the effluent never exceeds 0.2 cc. and usually averages 0.1 cc.

Excessive infiltration and the extreme temperatures in winter cause the sewage temperature in the tanks to become very low at times. This naturally retards digestion and requires frequent additions of lime. The lime is introduced through the gas vents by means of a drop bottom bucket, which deposits the lime on the sludge with little disturbance. Tank temperatures range from a minimum of 42° to a maximum of 68° F. On account of the difficulty of maintaining alkalinity in cold weather, it may be necessary to install a separate sludge-digestion chamber in which heat can be applied.

Sludge is drawn from the Imhoff tanks at intervals of about one week, being more frequent in summer and less in winter. The sludge flows by gravity to the sludge sump, from which it is pumped to the sludge beds through a 6-inch cast iron force main by means of a diaphragm pump. A float and indicator, visible from the tanks, keeps the operator informed as to the depth of sludge in the sump. Tests of the sludge are made semi-weekly.

There are twenty sludge beds, all uncovered, each 16 ft. by 125 ft. in size. Practically all of our sludge has been taken by farmers for fertilizing purposes. A portion has been conveyed to lagoons for filling low lying portions of the ground in the vicinity of the plant.

From the Imhoff tanks the effluent flows to the chlorinating chamber where chlorine is applied by means of a Wallace & Tiernan (type ADAF) direct feed apparatus. There are three sets of equipment, two in operation with one set always in reserve. The period of detention in the chlorinating tank is about 20 minutes, which with the interval of flow through the effluent sewer totals about 30 minutes at the average rate of flow. The usual orthotolidine tests for residual chlorine are made daily, or more frequently as flow conditions require. Chlorine is added in the proportion of 8 to 12 parts per million to get satisfactory tests. The daily consumption of chlorine is about 310 lbs., or a total of about 28 tons for six months of chlorination per year. The chlorine comes in one-ton drums, shipped in multi-unit tank cars.

All tests and operating methods are carried out in close conformity with the manual of operation issued by the State Department of Health, Division of Sanitation.

Three operators are required, each working an eight-hour shift. One of these operators is an engineer and is in direct charge of plant operation under the Department of Public Works. Each operator makes a daily report, or record, showing the operating conditions during his shift, with notes on any items of special interest. The information for our monthly reports to the state is taken from these daily records by the engineer in charge.

A water wheel, located in a by-pass between the chlorinating chamber and the effluent line, develops a maximum of sixteen horsepower and operates the sludge pump, fresh water pump and an electric generator for light and power. The opening of the turbine gate automatically diverts the flow from the weir box through the turbine.

The source of water supply is a 300-ft. drilled, free-flowing well which furnishes an abundant supply of pure water for washing and sprinkling.

Since the construction of the plant the screens have been covered to protect the men from the weather; the tanks have been fenced in; five acres of lawn have been graded and seeded; swampy places have been drained;

roadways laid out; ornamental shrubs set and white pine, white and Norway spruce, balsam, larch and locust trees to the number of 60,000 have been planted.

We are very grateful to the state authorities and to other sewage plant operators, and especially to Mr. Ryan of Rochester, for their valuable help and advice at times when we have encountered difficulties.

Discussion

BY H. BURDETT CLEVELAND

Consulting Engineer, New York City

Mr. Bergman's paper on the Jamestown, New York, sewage treatment plant gives a very complete description of the essential features of the design of the plant as to capacities, detention periods and operation.

It may also be of interest to state some of the main factors which influenced the design of the plant and some of the special conditions which governed the layout.

Since the logical site for sewage treatment works near the original outlet and at a point some four miles east of the city afforded opportunity for locating the plant well away from highways and 2000 feet distant from the nearest farmhouse, the use of Imhoff tanks for sedimentation and of open sludge drying beds fitted the conditions best, both in respect to first cost and regarding ease and economy of operation, since no special precaution against odor production was necessary.

Based on gaugings of the flow in the outfall sewer, the plant has a capacity for 5 m. g. d., which allows for a 10-year population increase.

A vote on authorization by the taxpayers for the construction of the plant was taken two years after the preliminary cost estimate was made, with no revision made in the appropriation to be voted upon, following a period of rising prices.

Consequently the cost of the plant, because of increased unit costs, and of other factors such as the requirement that chlorinating apparatus should be installed on construction, could not be kept down to the original estimate.

The estimate of cost made when the plans were completed was $160,000, which included reconstruction of a portion of the outfall sewer. The plant cost $180,000 or $3.60 per capita, a low cost for a plant providing Imhoff tank sedimentation, chlorination and sludge drying beds.

Every effort was made in the design to provide for maximum economy in first cost consistent with the construction of an effective plant. As an instance of this may be cited the housing of the chlorinating room and of the sludge pump room, with an 11-foot difference in elevations, under one roof.

Jamestown is particularly fortunate in its location with respect to sewage disposal. The dilution afforded by the considerable flow in Cassadaga Creek, reached by the trunk sewer four miles long constructed in 1899, rendered unnecessary a high degree of treatment, especially since the district for many miles below the outlet is sparsely settled. A reasonable degree of treatment was suggested and approved by the State authorities, consisting of sedimentation in Imhoff tanks followed by chlorination during the summer and fall months.

A study was made of the desirable elevation scheme of the treatment plant in connection with the fact that the trunk sewers in the city, and at times the outfall sewer, were heavily overtaxed by ground water infiltration and with the fact that the trunk sewers in the city were not deep enough to take some sewage and industrial waste now discharged directly into the Chadakoin river.

This latter condition had to be considered in connection with the decision to utilize the head which would be made available by the reconstruction of the lower end of the outfall sewer to generate power at the plant from the sewage flow.

A 15-foot head was thus created and it was found desirable to conserve this hydraulic head in view of the fact that, if a second outfall sewer should later become necessary, such a trunk could be laid on a flatter slope and with somewhat larger pipe than the present outfall and at elevations 10 or 12 feet lower than the present trunk sewers, thus extending the service to low-lying properties.

The turbine penstock, which was placed at the outlet end of the third compartment of the chlorinating chamber, is fed over a separate weir 0.6 feet lower than the weir ordinarily passing the effluent from the chlorinating chamber, in order that the flow elevation from the chlorinating chamber may not be lowered unduly if the turbine gate should at any time be opened sufficiently to pass effluent through the turbine at a rate exceeding the sewage flow to the plant.

Under these circumstances it was of definite economic value to the city to provide for development by the plant of its own power for use in sludge pumping, lighting and heating and, at some future date, for furnishing part of the power required for the activated-sludge process, should this process for more complete treatment of sewage be adopted in the future.

A 17-inch-D type Samson horizontal shaft turbine was installed, which on a rate of flow of 5 m. g. d. develops 16 hp. The turbine was installed in an open penstock with the shaft and gate mechanism extending through the concrete wall into the pump room.

At the time the plant was designed, power requirements for the activated sludge process were about 20 hp. per million gallons of sewage flow. It was expected that this would be reduced in the future and such reduction

in required power has occurred, since some plants are now using as low as 12 hp. per million gallons.

With 4 to 5 hp. required about one-fifth of the time for sludge pumping, a surplus, over pumping and lighting requirements, is available which could be supplemented by power which might be derived from sludge-digestion tanks, in the event that complete treatment of sewage should be required in the future and the activated-sludge process should be employed, following Imhoff tank sedimentation.

A special feature in the design of the chlorinating chamber, incorporated also in the Red Bank, N. J., plant with effective results, consists in the trapping of the flow of Imhoff tank effluent as it enters the chlorinating chamber and carrying the effluent about 54 feet in a 30-inch vitrified tile pipe before it discharges into the chlorinating chamber. Since chlorine gas is added to the Imhoff tank effluent under the curtain wall of the trap, the gas while being mixed with effluent does not come under a free surface of liquid until it has passed in a swirling course through the 30-inch pipe.

This insures better mixing, whether dry feed of chlorine or liquid feed is employed, and results in effective chlorination with less dosage than if the mixing pipe were not installed.

With respect to operating arrangements in the chlorinating room, since, at the time the plant was designed, one-ton containers for chlorine were coming into use as an aid to economy in the purchase of chlorine, a 15-inch I-beam trolley was hung under the roof of the pump room to permit the use of a chain hoist for handling chlorine drums, as well as to handle pumps and the turbine.

The support of this I-beam at the point where it projected from the building to facilitate the handling of chlorine drums had to be at an elevation higher than the wall plate of the building if a hip roof was built, but this was accomplished by constructing a jerkin-head roof, much preferable in appearance to a full length ridge roof.

Owing to the limited appropriations available, very little expenditure could be allotted in the design and construction toward making the plant at all ornate, an objective less important at the site of this plant than at many plant locations. Rather, the primary aim in the design, as must always be kept foremost, was to build for the city a permanent, serviceable and effective sanitation utility which would function economically both as to operating cost and fixed charges; and, also, to so arrange the structure that any future enlargement of the plant, either for increased capacity or for a higher degree of treatment, could be made without sacrifice of previous construction.

Editorial

The Fate of Bacteria in Polluted Waters

The removal of bacteria is an important function of sewage treatment processes, but in recent years its importance as a measure of efficiency of sewage treatment has been overshadowed by interest in the removal or stabilization of organic matter by biological oxidation. This changed viewpoint has been brought about by the knowledge that chlorination is more effective and cheaper than biological oxidation as a means of removing bacteria.

To the layman or the public health official the removal of bacteria may seem to be the primary function of sewage treatment, and in cases where protection of water supplies, oyster beds or bathing beaches is required, bactericidal efficiency is paramount.

There are several factors which contribute to the diminution of infectivity of the bacteria in sewage. The first barrier to the escape of bacteria is the treatment process, comprising, in complete treatment, oxidation, sedimentation and retention of the bacteria in sludge. The second barrier is the chlorination of the effluent. The third barrier is the self-purification of the stream or body of water into which the effluent is discharged. Finally, of course, the most potent barrier is the water filtration plant, but this does not enter into the field of this discussion, which is concerned with the third barrier, namely, self-purification of polluted waters.

Studies of stream self-purification by the U. S. Public Health Service on the Ohio, Illinois and Mississippi Rivers have included investigations of bacterial death-rates, as affected by variable factors such as dilution, time of flow, temperature and initial degree of pollution. The bacteria introduced from known populations into known flows have been determined and their variations in numbers traced downstream.

It might be assumed that the numbers of bacteria introduced in sewage would be at a maximum just below the point of discharge (assuming uniform dispersion) and that thereafter a decline in numbers would occur. Work on the Ohio River by the U. S. Public Health Service indicated that the maximum bacterial concentration was not found immediately below the sewer outfall, but some distance downstream, corresponding to from 8 to 24 hours of flow. Further work on this river and the Illinois River showed that the effect of dilution of a polluted stream by a less

polluted tributary might result in an overall increase, rather than a decrease, in the bacterial concentration.

These observations led to the experimental work reported in this issue by Hoskins and Butterfield and by Heukelekian. In both studies it was found that the total bacteria and the *coli-aerogenes* groups increased during the first 24 hours, then decreased rapidly, particularly at elevated temperatures of 30° to 37° C. The initial increase was greatest in the diluted samples.

It has been tacitly assumed that there should be no increase in such organisms as the *coli-aerogenes* group, normal inhabitants of the intestinal tract, when discharged into natural waters. Indications of such increase were usually ascribed to the effect of disintegration of clumps of bacteria. The present work indicates, however, that the *coli-aerogenes* organisms actually do grow in natural waters. This is a rather important implication, although most work in recent years has been pointing to such a conclusion. It hardly seems possible, however, to conceive of an increase of such a strictly pathogenic organism as *Bact. typhosum*, although epidemiological evidence indicates that this organism can live for months in feces.

The temporary increase in the numbers of the *coli-aerogenes* group might be ascribed to an increase in the so-called "soil" type, *aerogenes*, and not to the "fecal type," *coli*, but work by Ruchhoft *et al.* indicated that both types decreased at approximately the same rate in the Illinois River. Their results indicate that *aerogenes* had no appreciable advantage over *coli* in longevity in polluted streams. The differentiation was made both on the basis of Noble's medium, as used by Heukelekian, and as confirmed by such available differential tests as indol, methyl red, Voges-Proskauer and citrate.

Even though we must conclude that it is possible for *Bact. coli* to increase in numbers during the first day after discharge of sewage, the decrease thereafter is quite rapid. Within the first day's flow, however, the epidemiological significance of the viability of *Bact. coli* is of considerable importance. In this connection the typhoid fever epidemic at Chamberlain, South Dakota, recently reported by W. W. Towne, State Sanitary Engineer of South Dakota, is worthy of consideration. Sewage from a small Indian school was discharged into the Missouri River only four thousand feet above the water intake at Chamberlain. The water supply was insufficiently chlorinated temporarily. Twenty-nine deaths and 282 cases were reported for this village of 1500 persons. Such cases remind us that we must still be concerned first of all about the fate of bacteria in sewage disposal. In order to feel secure about the efficiency of disposal of sewage effluents, from a pathogenic standpoint, we need more information about the limiting effect on bacterial viability of such factors as dilution, sedimentation, food supply and bacteriophage.

Employment Service

(1) DESIGNER thoroughly experienced in design and construction of sewage treatment plants. Just completed one year with general contractor on sewage treatment plant job. Previous four years drafting and design work in sanitary engineering. Total experience twelve years since graduation. Age 37. Married. Assoc. Mem. A. S. C. E.

(2) M.S. in SANITARY ENGINEERING, 1932, Michigan State College. Seven years with the Michigan State Highway Commission. Municipal engineering, including construction of water mains and sewers. Assistant instructor in sewage operators school. Publications on trickling filters and stream pollution. Age 31. Married.

(3) SANITARY ENGINEER, graduate M. I. T., four years experience in design of sewers and sewage treatment works, five years experience in investigating industrial wastes, designing and operating sewage testing stations, and investigating and developing methods and apparatus for sewage treatment. Three years as asst. supt. of large activated-sludge plant. Desires position to design or operate treatment works or to aid in the development of new processes and apparatus for sewage treatment. Age 36. Married.

(4) CHEMIST AND BACTERIOLOGIST, university graduate, six years superintendent of water filtration plant, past five years in sewage works laboratory, in charge of plant control. Recent experience in sludge filtration and disposal. Age 37. Married.

(5) SANITARY ENGINEER, M.S. from Michigan State College. Experience in highway and railway work. University work in soil bacteriology. Age 25. Single.

(6) SANITARY CHEMIST AND BACTERIOLOGIST, B.S. in Chemical Engineering, M.S., four years experience in sewage and water treatment, principally research and development at state experiment station, recently with prominent consulting sanitary engineer, publications. Age 27. Single.

(7) SANITARY ENGINEER. More than ten years experience in designing, building and servicing mechanical equipment used in sewage treatment works, such as screens, clarifiers, digesters, aerators and pumps. Design and construction of paper mill and beet sugar factory. Age 37. Married.

(8) SUPERINTENDENT of sewage works. Ten years experience as Superintendent of small Iowa sewage treatment plant. Has also had charge of municipal garbage incineration works. References. Age 39. Married.

(9) SANITARY ENGINEER. Technical school graduate, nine years experience sewage collection and treatment and water distribution and purification. Investigations, reports, design, construction, operation, chemical and bacteriological analyses, research and development, sanitary equipment sales and promotion. Familiar with engineering state and municipal organizations in eastern and mid-western states. Desires position as sales engineer, designer, or operation superintendent. References and details of experience on request. Remuneration secondary to permanent connection with future. Age 30. Married.

Proceedings of Local Associations

Pennsylvania Sewage Works Association
Seventh Annual Conference

State College, September 5 to 7, 1933

The Seventh Annual Conference of the Pennsylvania Sewage Works Association was held in "Old Main" at the Pennsylvania State College, State College, Pa., Tuesday to Thursday, September 5 to 7, 1933.

The conference was one of the best in the Association's history and although the attendance showed the effects of the present business depression, there were 90 registrants and 84 in attendance at the annual banquet. The Association lost 2 members by death and 7 by registration but gained 18 new ones during the past year, making its total membership 147.

Professor Raymond O'Donnell, President, ably presided at the conference, aided and abetted by its capable and perenially genial Secretary-Treasurer, L. D. Matter.

Tuesday evening, Major F. E. Daniels of the Pennsylvania Department of Health opened the conference with an instructive talk "Practical Tests at Sewage Works," in which he demonstrated the actual tests, showed some unique and time saving apparatus, and gave much helpful advice based upon his long experience.

Wednesday morning, Dean R. L. Sackett of the School of Engineering welcomed the conference in a most interesting review of the progress of sanitary engineering. A "Trouble/ Hour" followed with papers dealing directly with practical problems of operation and their solution.

A. B. Cameron's paper upon successful handling of grease and skimmings by chlorination at the Erie, Pa., plant; the various details of design cited by Roy L. Phillips of Meadville, Pa., as means of forestalling trouble; Frank Altemus' description of screen and pump suction, grit chamber and miscellaneous problems at Norristown, Pa., including his leaving a flooded plant by boat; R. R. Cleland's experience with the ever present sludge problem at State College, Pa.; and L. E. Burnside's comments upon sludge and supernatant handling at Sharon, Pa.—were timely, interesting and helpful.

Following this technical session an important business meeting was held at which the report of the Executive Committee was heard and final action taken disapproving a proposed merger with the Pennsylvania Waterworks Operators' Associat n; a report by the Committee upon Sewer Rental

Laws, giving the progress made in having a rental law passed by the General Assembly and later vetoed by the Governor, together with suggested improvements in the law, was accepted and the Committee continued to give the subject further study and to report thereon; and a report was received from the Committee to consider a Short Course School for Sewage Works Operators and the Licensing of Operators. This Committee was enlarged to include representatives of Pennsylvania State College, the Pennsylvania Department of Health and the operators, and directed to confer with the College, the Health Department and the Pennsylvania Waterworks Operators' Association in an effort to arrange a short course of instruction for the coming year and to give further study to the subject of operators' licensing.

Other business included the report by the Committee on the Study of Gas Explosion Hazards, the usual Resolutions and Auditing Committees and the Nominating Committee, whose recommended nominees for the year 1933–34 were unanimously elected as follows: Harry J. Krum, Allentown, *President;* Roy L. Phillips, Meadville, *1st Vice President;* E. B. Wagner, Downingtown, *2nd Vice President;* L. D. Matter, Wilkes-Barre, *Secretary-Treasurer;* J. R. Hoffert, Harrisburg, *Editor;* C. A. Emerson, Jr., New York City, H. E. Moses, Harrisburg, *Representatives, Board of Control.*

In the afternoon, "Operating Experiences in New York State," by Charles C. Agar was a valuable review of actual operating experiences interspersed with humorous incidents and well selected lantern slides.

"Excessive Ground Water in a Sewer System and Its Effect on Sewage Plant Operation," by C. A. Emerson, Jr., forcefully outlined the need for tight sewer lines which was further developed in an interesting discussion.

John L. Fertig's able presentation of the timely "Application of the Sewer Rental Law" with particular reference to Pennsylvania, showed clearly the rising interest in and advantages of rental financing; and E. R. Queer of Pennsylvania State College described some careful experiments to determine accurately "Heat Transfer from a Heating Coil to Sludge."

The Annual Banquet in the Nittany Lion Inn with H. E. ("Ted") Moses as a real *Master* of Ceremonies was a genuine success, as usual. Following the introduction of distinguished members and guests, the party disposed of an honest-to-goodness supply of material suitable for temperature controlled digestion and followed with a final course of sewerage "hard nuts to crack" in the form of a round table discussion of real sewerage problems which kept every one alert until "Jose Reed"—the man from Spain—roused the risibilities of the crowd with dialect stories and instrumental acrobatics.

Thursday morning the conference proper ended with a description of the two modern activated sludge treatment works at Lancaster, Pa., by John F. Laboon, one of the designing engineers; "The Oxygen Demand Test and Its Application to Sewage Treatment," ably presented by J. K. Hos-

kins, of the U. S. Public Health Service; and an illustrated paper on "The Mechanical Dewatering of Sewage Sludge on Vacuum Filters," by E. D. Flynn, of Oliver United Filters.

A joint golf tournament in the afternoon with members of the convening Pennsylvania Waterworks Operators' Association, with a mutually satisfactory ending, concluded a worthwhile conference.

J. R. HOFFERT, *Editor*

Reviews and Abstracts

H. W. STREETER

The Purification of Beet Sugar Wastes
Introductory Note

By H. W. Streeter

The rapid development of the beet sugar industry in Great Britain and in various parts of the United States has been attended by the problem of instituting proper disposal of the wastes from this industry, which are highly organic in character and when discharged into streams without treatment have caused serious pollution. With a view to informing readers of This Journal concerning recent advances made toward a solution of this problem, abstracts of three important reports on the subject, all issued since the first of the current year, have been brought together in the pages immediately following this introduction.

In the British report by Messrs. Richards and Cutler, which has been prepared under the general direction of Dr. H. T. Calvert, Director of Wastes Pollution Research for the Department of Scientific and Industrial Research, detailed results are given of an exhaustive series of chemical and biological studies embracing a period of three years, looking toward the establishment of the most effective and economical methods for disposing of beet sugar wastes without injury to streams, which in the British Isles are relatively short and small in volume. It is significant in this connection that these investigations have been made by an agency of the British Government with active coöperation from the beet sugar industry itself, which appears to recognize fully its joint responsibility in the problem. The extraordinary growth of this industry in Great Britain is evidenced by the statement in the report that the quantity of beet sugar manufactured in that country increased from 7000 tons in 1922–23 to nearly 300,000 tons in 1929–30.

The two reports issued, respectively, by Messrs. Eldridge and Theroux and by Dr. Max Levine deal with beet sugar wastes disposal in Michigan and Iowa, where particularly favorable conditions exist for the growth of this industry. In studying these two reports in conjunction with that of the British workers, the reader is impressed by the essential similarity of the general problems presented by beet sugar wastes in the two countries and by the striking agreement shown in the universal conclusion reached from these three investigations, particularly as regards the efficacy of bio-

logical treatment on trickling or percolating filters in dealing with the more highly organic "process" wastes from the industry. The only noteworthy points of divergence in these conclusions appear to have been: (1) with respect to the treatment of these wastes by activated-sludge process, which yielded satisfactory results in the British tests, but was not found entirely successful in the Michigan studies, owing to excessive foaming during aeration, and (2) with respect to the re-use or re-circulation of certain wastes in the beet sugar factories, which is regarded highly by the British observers as a supplementary measure, but unfavorably by the Michigan workers, on the ground that undue concentration of these wastes may result from such a practice. The advantages of controlled treatment of "process" wastes from beet sugar manufacture in conjunction with municipal sewage are stressed by Messrs. Eldridge and Theroux and those of ponding by Dr. Levine. Neither of these two measures appears to have been considered seriously by the other workers, though local conditions doubtless may have their part in these divergences of viewpoint.

All three of the reports abstracted are notable contributions to the subject and deserve careful study in the original text by those who are concerned with similar problems.

The Purification of Waste Waters from Beet Sugar Factories

BY E. H. RICHARDS AND D. W. CUTLER

British Dept. of Scientific & Industrial Research, Water Pollution Research, *Technical Paper* No. 3, 157 pp. (December, 1932).

With the rapid growth of beet sugar manufacture which has developed in Great Britain since 1922, several cases of serious pollution of streams have occurred, owing to the large volume and polluting character of the wastes and the relatively small volume of the streams in that country.

Realizing that this pollution could not be avoided unless the manufacturing processes could be so altered as to reduce the quantities of wastes discharged, or some practicable means be devised for purifying the effluents, the Department of Scientific and Industrial Research arranged, early in 1927, for preliminary experiments to be made at the Rothamsted Experimental Station. Three possible methods were first tried on a laboratory scale, namely: fermentation, with lime; oxidation on percolating filters; and bio-aeration with activated sludge. These preliminary experiments indicated that fermentation with lime was not alone satisfactory. Biological filtration gave promising results, as also did bio-aeration, but the prospects of large-scale success seemed less promising in the latter case

than in the former; hence expansion of the experiments in biological filtration to a semi-plant scale was considered justified.

These experiments were carried out during the three beet sugar seasons, 1927–30, on large experimental filters built at Colwick. The laboratory experiments have been continued at Rothamsted meanwhile. The work, which has been done in coöperation with the beet sugar industry, has included a study of the chemical and biological changes occurring in the filters and in wastes at different stages of treatment. At the same time, realizing that the ideal solution of the problem would be to alter the manufacturing processes so that no wastes need be discharged, several factories have modified their processes for total or partial re-use of water, with consequent reduction in the volume of effluent discharged.

The manufacture of beet sugar is a seasonal industry, beginning in October and lasting about 100 days. On arrival at the factory the beets, with tops removed, are unloaded and conveyed by carriage along flumes to the washers. Extraction of the sugar may be divided into the following operations:

The beets are washed in machines to remove soil and debris, 2.5 to 3.5 mil. gals. of water per 1000 tons of beets being required. The beets are sliced into "cossettes," which are treated with hot juice or water in a battery of diffusers in which the sugar is extracted. The spent cossettes are pressed in filter presses and the residue disposed of on land, or as cattle food. The filtrate from the presses, together with the washings of the diffusion battery, is known as "process" water and amounts to 300,000 to 500,000 gals. per 1000 tons of beets extracted.

The sugar solution discharged from the diffusers is purified with lime and then treated with carbon dioxide, the precipitated calcium carbonate carrying down impurities. The liquid is filtered in presses to remove spent lime, purified further with lime, carbon dioxide and sulphur dioxide and then filtered. The purified juice is evaporated in multiple-effect evaporators and vacuum pans and cooled to crystallize the sugar. The extract is then centrifugalized to separate crystals from the molasses. About 3 m. g. of water per 1000 tons of beets are required for cooling purposes. This water is often used as "flume" water, to convey the beets into the factory.

The wastes from the process, together with their volumes per 1000 tons of beets extracted are as follows:

1. Condenser or cooling water, 2.5 to 3.5 m. g.
2. Transport or "flume" water, 2.5 to 3.5 m. g. (often the same as condenser water).
3. "Process" water, 300,000 to 500,000 gallons.
4. Water for conveying spent lime to lagoons, 40,000 to 80,000 gallons.
5. Washing floors, plant, etc., very small amounts.

Chemical Studies.—As the condenser water is relatively unpolluted and the lime-conveying water is absorbed in the ground or evaporated into the atmosphere, the main problem presented is the purification of the process water, which is highly polluted in character. This water varies in composition, but an average contains 0.1 to 0.2 per cent sucrose and has a 5-day B. O. D. of 1000 to 2000 p. p. m. Laboratory experiments with the treatment of this water resulted as follows.

Fermentation with additions of lime reduced the B. O. D. by only 35 per cent, though the oxygen absorbed from permanganate was reduced by 80 per cent. In the laboratory experiments of the bio-aeration and biological filtration treatments, over 90 per cent reduction in B. O. D. was obtained.

The advantage of biological oxidation on percolating filters led to further study of this process with respect to the effects of (*a*) the rate of filtration, (*b*) strength of liquor supplied to the filters, (*c*) preliminary dilution of the diffusion and pulp-press water with effluent from the filters, (*d*) size and character of filtering material, (*e*) depth of filter, (*f*) addition of nitrogen in different forms, and (*g*) preliminary fermentation of diffusion and pulp-press water to convert part of the sucrose into organic acids.

From the laboratory and plant scale experiments, it was concluded that the conditions necessary to achieve 90 per cent purification of process water by biological oxidation on percolating filters 6 ft. deep are: (1) The waste water should be settled to remove the major portion of suspended matter and diluted to give a liquid in strength equivalent to a solution containing 0.1 per cent sucrose. The dilution may be affected by river water, effluent from the filters or transport and washing water. (2) The diluted waste water should be filtered at a rate not exceeding 100 or 150 gal. per cu. yd. of filtering material per day. (3) The most suitable medium for filters is a hard insoluble material such as gravel, flint or slag; it should be graded from $^{3}/_{8}''$ to 1″ and should be free from dust.

Biological Studies.—A survey of the biological population of the filters at Colwick was made to find out the kind of organisms normally present and, if possible, their functions. Estimation of the volume and composition of the film and of its sugar fermenting power were made, and the numbers of organisms of different groups were counted.

A greater volume of film occurred on the finer filter media. The film increased during the first 4 or 5 weeks and then remained constant in amount unless sloughing was caused by some external agency. The volume of film decreased gradually with the depth of the filter.

The organisms present included bacteria, fungi, yeasts, algae, protozoa, rotifers, nematodes, insect larvae and oligochaetes. There was little difference between the population of the different filters; the smaller organisms developed fully after 2 or 3 weeks, while the larger ones developed more slowly.

The number of organisms decreased with the depth of the filters except for the testaceous rhizopods and paramoecia, which were more common at the bottom. The protozoa present were largely meso-saprobic forms, similar to those in sewage filters and in soil. Among the bacteria present were a number of nitrogen-fixing organisms.

Inoculation with medium from a sewage disposal works percolating filter made no apparent difference to the purification of the effluent or to the population developed in the filters, except for the introduction of insect larvae at an earlier stage than occurred in uninoculated filters.

As far as was observed, a rate of flow up to 300 gal. per cu. yd. per day did not wash organisms out of the filters.

Appendices.—The report contains five appendices, dealing with the following special phases of the investigation:

1. Press Water. An analysis of its composition indicated that about $^3/_4$ of the solids were in solution and included sugar, protein, salts and a trace of saponin. Experiments on coagulation of the suspended matter have shown that fresh powdered lime is most effective with maximum precipitation at pH 10.5 to 11.0. Results of four experiments in the fermentation of press water are given. They show that the rate of conversion of sugar depends mainly on temperature and is a maximum at 35° to 40° C.

2. Methods of Analysis. Certain modifications in the usual methods of sewage analysis were necessary in dealing with the beet sugar effluents, notably with respect to pH value, sugar, oxygen absorbed from permanganate, 5-day B. O. D., total solids, suspended and dissolved solids and total nitrogen. These modifications are described in detail.

3. Time of Contact of Percolating Filters. The method followed in determining the time of contact between the liquid and the filtering medium is described, based on that of Clifford. According to this method, liquid undergoing treatment is applied until conditions are constant; then at a recorded time a small amount of salt solution is distributed over the filter. The concentration of salt in the effluent is measured at equal intervals of time until practically all of the salt has been removed. The time of contact is calculated as $\Sigma PQ/\Sigma Q$, in which P is the salt concentration at each time of sampling and Q is the interval of time from the addition of the salt solution. In practice, it was found that the time of contact thus calculated was approximately equal to the time required for half of the salt to be removed from the filter. This time is less than half of the total time during which the salt is discharged. Figures on the relation found between rate of flow and time of contact are given; also on the increase in time of contact with development of films in the filter medium.

Appendices 4 and 5 deal, respectively, with a description of the biological purification plant at the beet sugar factory at Cantley, Norfolk (erected largely as a result of the earlier results shown at Colwick) and with

a method developed by Houston for estimating sugar and the sugar-fermenting power of bacterial growths.

A bibliography of 45 references on beet sugar wastes and their treatment is given at the end of the report. H. W. STREETER

Studies on the Treatment of Beet Sugar Factory Wastes. Report No. 1

BY E. T. ELDRIDGE AND F. R. THEROUX

Michigan Eng. Expt. Sta. Bull. No. 51, 36 pp. (May, 1933).

The report deals with studies made in Michigan during the 1931 and 1932 sugar beet campaigns. The 1931 studies were limited to bibliographical search and survey at each factory in operation. In 1932, a study was made of the method applicable to "process waste" which was found during 1931 to contain most of the organic matter discharged from the sugar beet factory.

Summary of 1931 Survey.—Conclusions drawn from the 1931 studies were:

1. The four major beet sugar wastes are flume water, process water, lime-cake drainage and Steffens waste.

2. Disposal of these wastes may be accomplished by elimination, re-use, treatment, utilization or dilution.

3. Lime-cake drainage may be eliminated by conveying the cake to the field by some means other than water transportation.

4. Diffusion battery wash water and pulp press water can be eliminated by using continuous instead of battery diffusers. The process is more expensive and less efficient in the extraction of sugar.

5. Re-use of flume water after clarification is possible but not practicable unless water is scarce. Discharge of the clarified water into a stream is preferable to discharging after re-use has caused an accumulation of solids in solution.

6. Re-use of process water is practicable to some extent, but accumulation of foreign materials will eventually interfere with purification of the sugar.

7. Treatment of flume water should consist of efficient clarification rapidly accomplished by screens and settling basins, which should be equipped for continuous sludge removal or may consist of ponds arranged in parallel.

8. Process water should be treated separately from flume water. Although fermentation and biological filtration have shown some degree of success methods for treating process water will require further study.

9. Treatment of Steffens waste would be difficult and costly. Utilizaof this waste should be attempted by trying to find a market for disposing of the by-products, of which potash seems to be of most value and the fertilizer market, the best outlet.

Studies of Process Water Treatment During 1932.—The studies during the 1932 campaign were carried out at an experimental plant of the Lansing beet sugar factory. At this factory the pulp, after extraction of sugar, is mixed with the water used for washing the diffusion batteries and pumped to the dryer house. Here it is screened, removing most of the water, and then goes to pulp presses and finally to drum driers. The water from the pulp presses is pumped back over the screen to remove larger particles passing the press. The combined water passing through the screen is known as "process" water.

Measurements of this waste showed it to be 0.7 m. g. d. in volume, or 650 gal. per ton of beets. The B. O. D. of this waste averaged 840 p. p. m. and varied from 700 to 1125. The total solids averaged 1800 p. p. m. varying from 1460 to 2250. Of the total solids, 63–79 per cent were volatile. The quantity of total and volatile solids was influenced largely by the sucrose content of the waste.

Chemical Precipitation Studies.—Laboratory studies were made with lime alone and together with ferric chloride, for the purpose of finding the quantity of these reagents necessary for adequate treatment and also the possible reduction in B. O. D. From four series of tests, it was indicated that the optimum amount of lime alone for good clarification was about 500 p. p. m., which effected a reduction B. O. D. from 720 to 80 p. p. m. (89 per cent). With 50 p. p. m. of ferric chloride the optimum lime dose was 600 p. p. m., the B. O. D. removal being 90 per cent. Only a slight advantage was found from adding ferric chloride.

Similar tests were made with an experimental plant, consisting of a 2400-gal. fill-and-draw tank equipped with a motor-driven agitator. The results compared favorably with the laboratory experiments. In this case the addition of ferric chloride in amounts as low as 15–20 p. p. m. gave much better clarification with lime than when lime alone was used. The minimum effective amount of lime was 600 p. p. m. The degree of B. O. D. removal depends on the sucrose content of the original waste, being 80–82 per cent after 2 days' settling with a sugar content of 400–500 p. p. m.

With an average of 650 gal. of process water per ton of beets and assuming that this volume is treated with 600 p. p. m. of lime at $6 per ton, the cost of lime per ton of beets would be 0.9 cent. If 50 p. p. m. of ferric chloride, costing $15 per ton of 40 per cent solution is added with the lime, the cost of that chemical would be 0.5 cent, bringing the total to 1.4 cents per ton of beets. The cost of tank installation required for a 1000 ton factory is estimated at $5000–$7000.

Activated-Sludge Process Tests.—An experimental activated-sludge treatment plant was set up at Lansing, consisting of an aeration tank, a small Simplex aerator, a settling tank and a return-sludge pump. The aeration tank was filled first with process water and aeration was started. Trouble was experienced immediately from a thick foam, which became 8 inches thick within an hour and prevented effective aeration. Setting the aerator higher helped the situation, but did not remedy the difficulty. The settling tank became covered with a thick mat which went over with the effluent and carried much suspended matter with it. During this time there was some reduction in B. O. D. but little clarification or sludge settlement.

A 1:1 mixture of process and flume waters was aerated for four weeks, but foaming was again experienced and to a greater degree. After the sludge in the aeration tank had been built up to 1800 p. p. m., various aeration periods were tried on different mixtures of the two wastes. With process water alone, 24 hours was necessary to remove the sucrose and reduce the B O. D. to 65 per cent. A 3:1 mixture of process and flume waters required 18 hours with a 72 per cent reduction of B. O. D. A 1:1 mixture required 12 hours, with 80 per cent removal of B. O. D.

The results of this study showed that activated sludge could not be developed by aeration of process water alone, but could be built up with mixtures of process and flume waters. A number of factors are not favorable to using the activated-sludge method with process water, the most outstanding one being the tendency of the waste to foam and the high cost of equipment necessary to provide a 12-hour aeration period. With the equipment used, it was impossible to correct foaming so as not to interfere with aeration. Unless this foaming tendency can be corrected, activated-sludge treatment probably cannot be adapted to this waste.

Digestion of Mixtures of Sewage and Process Water Sludges.—One possible method considered for disposing of "process" water was by mixing it with city sewage, as the location of several beet sugar plants in Michigan would favor this method. Such a method would affect principally the digestion units in a sewage treatment plant; hence a study was made of the digestion of mixtures of solids representing various proportions of process water sludge and sewage sludge.

The results of these studies were measured by gas production per gram of volatile matter. These results indicate that process water up to 10 per cent may be mixed with sewage without affecting the digestion of sludge. Mixtures containing 14 to 53 per cent of process water showed slightly retarding effects on gas production during the initial stages, but within 4 weeks produced about the same amount of gas as that from sewage sludge containing the same weight of volatile matter. With a mixture containing as high as 70 per cent of process water, gas production was

seriously retarded. It is concluded from these results that sugar beet process water can be added to sewage in approximately equal parts without seriously affecting digestion of the sludge.

A list of 51 references on beet sugar wastes and their treatment is appended to the report. H. W. STREETER

Purification of Beet Sugar Wastes

BY MAX LEVINE

Am. Jour. of Pub. Health, **23**, No. 6, 585–90 (June, 1933)

The paper is based on observations made over a period of 3 years at a large sugar beet factory and considers the relative efficiencies of ponding and biological treatment on trickling filters of various types.

The wastes studied included: (1) pulp or battery water (0.7 m. g.) which is warm (40–50° C.) and high in B. O. D. (800–1300 p. p. m.); (2) wheel water (3.5 m. g. d.) used in fluming the beets, containing mud, silt, etc., and with a B. O. D. increasing from 150 to over 500 p. p. m. as the season advances; (3) Steffen's wastes (0.2 m. g. d.), a liquid residue from the recovery of sucrose, high in solids (20,000 p. p. m. total and 13,000 p. p. m. volatile) and in B. O. D. (3600 to 5000 p. p. m.).

Settling of pulp water in open ponds for 24 hours reduced the permanganate oxygen consumed 77–80 per cent, but reduced the B. O. D. only 13–22 per cent. Volatile solids were reduced 50–62 per cent and pH fell from 6.6 to 4.5. The temperature was always high enough (22–32° C.) for efficient biological purification on filters.

Addition of lime (2 tons per m. g.) to pulp water after settling did not produce better effluents than simple sedimentation, as regards B. O. D.

Ponding wheel water reduced suspended matter by 93–98 per cent but improved B. O. D. very little. Wheel water temperatures during the latter part of the manufacturing season (October to January) may be so low that after ponding, the effluent may be close to freezing temperature and unsuitable for biological purification.

Passing a 1:5 mixture of pulp and wheel waters through a Dorr thickener, with one hour of settling, reduced suspended solids 90 per cent and organic nitrogen 50 per cent. Filtration of this effluent through 9 feet of $^1/_2$- to $1^1/_2$-inch quartzite at 2.0 m. g. d. reduced volatile solids by 72.4 per cent, organic nitrogen by 95.4 per cent, permanganate oxygen consumed by 80 per cent and B. O. D. by 90 per cent. Coarser material (1 to 3 inches) gave inferior effluents.

Coarse cinders ($^1/_2$ to $1^1/_2$ inch) were particularly efficient, giving reductions over 95 per cent when the rate of application was 2.0 m. g. d.

Pulp water can be purified efficiently on trickling filters if a suitable method for removing suspended solids could be devised.

Steffen's waste, when diluted with 20 parts of other wastes (pulp and wheel waters), was amenable to biological purification on trickling filters.

H. W. STREETER

Design and Operation of the Esholt Works of the Bradford Corporation

BY H. WONTNER-SMITH

Paper Read at Annual Summer Conference of the Institute of Sewage Purification Held at Bradford, England, July 6–8, 1933

Abstracted in the *Surveyor*, **84**, 33–9 (July 14, 1933)

The Esholt Works are located on a 1900-acre tract of land acquired for the purpose and have been designed and constructed in large part since the war. Actual operation of the plant began in 1926 following the completion of certain units; other units have been placed in use as they have been completed.

The plant has been designed to treat a sewage containing large quantities of wastes from the textile industries such as wool scouring, piece washing and dyeing of wool, cotton and silk goods. The contributing population total 287,000 and produces 18 m. g. d. of dry weather flow of sewage equivalent to 63 gallons per capita, about half of which is industrial waste. The average daily flow for a representative year, including storm water, was $26^3/_4$ m. g. d. The average daily dry weather flow for eight or nine hours during the working day is at the rate of 30 m. g. d., the basis used in much of the plant design. This day flow is of abnormal strength as indicated by the following representative analyses:

	Parts per Million	
	Dry Flow	Average Flow
Oxygen absorbed (4 hr. at 80° F.)	474	246
Alkalinity (to methyl orange)	2009	815
Nitrogen as free ammonia	101	44
Nitrogen as albuminoid ammonia	95	29
Suspended solids	3740	1450
Grease	1680	890

The city has certain legal authority for controlling the quality of trade wastes admitted to sewers. Specific exemptions from these restrictions result in wool scouring wastes from the 60 plants being of two main classes (*a*) crude wool suds and (*b*) treated wool suds, known as seak tank effluents. Representative analyses of these two classes indicate that of 16 firms con-

tributing treated waste the grease content is reduced to 1440 p. p. m. in comparison with 22,200 p. p. m. of the average untreated waste from 44 firms.

Detritus and Storm Water Tanks.—The incoming sewage first passes over a detritus pit 11 ft. deep and having a capacity of one-fiftieth of the dry weather flow, for the interception of sand and other coarse waste products, from which about 7300 tons of material are dredged annually. The sewage next flows through one of eight mechanical revolving screens each $7^3/_4$ ft. in width and provided with mechanical scrapers. The screens are not at present in use because it is found that the absorbent and thickening material removed by them is necessary to promote good pressing of sludge. Accordingly, this material is passed to the detritus tanks and there removed from the partially settled sewage by means of scum boards and mixed with the tank sludge when the tanks are emptied.

There are two detritus tanks each 150 by 40 ft. in plan and $11^1/_2$ ft. deep, providing a flowing through velocity of 4 ft. per minute when operated singly as is the custom except during times of storm flow. The settled sludge, amounting to 5 tons per million gallons of dry weather sewage flow, gravitates to a sludge screening plant and then to the press house. The effluent passes through a storm water bay from which it is diverted either to the chemical precipitation plant or to the storm water tanks. These latter tanks, 7 in number, have a total capacity of 11 m. g.

The practice now is to further treat all sewage up to 60 m. g. d. by chemical precipitation. For this purpose three lines of cast iron, inverted syphon pipes each 4 ft. in diameter and 2250 ft. long are provided to carry the partially settled sewage across the Aire valley to the site of the precipitation works. The syphons are each cleaned weekly by the passage through them of a wooden ball 3 ft. 9 in. in diameter.

Mixing and Precipitation Tanks.—The syphons discharge to a shallow bay giving entry either to the mixing or precipitation tanks. Sulphuric acid, spent liquor from sludge pressing, sludge from the secondary precipitation tanks and humus from the catchment ponds are mixed with the partially settled sewage in mixing tanks having a total capacity of 445,000 gallons. The tanks have three serpentine channels, two of which are provided with mechanical stirrers, motivated by the flow of sewage, and which have a detention period of 40 minutes.

The 20 primary precipitation tanks are each 140 ft. long, 60 ft. wide and $7^1/_2$ ft. deep and have a total capacity of $7^1/_2$ m. g. The 20 secondary tanks are each 140 × 65 ft. in plan and 10 ft. 2 in. deep and contain $11^1/_2$ m. g. The sludge from the primary tanks gravitates to the press house. The secondary sludge is returned through the mixing tanks to be deposited in the primary tanks. About 700 tons of wet sludge are collected daily.

Acid is added only during the hours when the wool scouring liquors are

present in the sewage. The primary tanks are operated as single units and retain the great bulk of precipitated sludge. They are worked until they are full of sludge, which usually requires about 3 months, when they are shut off for emptying. The secondary tanks serve mainly as equalizers of the alternating acid and alkaline liquors to insure a constant quality of influent to the filters. Research has indicated that a pH value of 6 for the tank effluent gives the best results. It is not always possible to raise the pH value from 4.5 to this desired figure but is maintained at pH 5.5.

Sulphuric Acid Plant.—This plant is of the modern, chamber type and supplies 9000 tons of acid annually; further requirement of 5000 tons is obtained from the city gas department. About 5000 tons of iron sulphide and 130 tons of nitric acid are used to produce the raw acid or brown oil of vitriol which requires no further purification for the purpose. The working efficiency of the plant is 97 per cent.

Screen House and Bacterial Filters.—The tank effluent is conveyed through a rectangular conduit to fine screens of copper plate of three sizes, one behind the other, at a distance of 30 inches. The front screen has openings of $^1/_4$-inch diameter, the second and third each have holes $^1/_8$-inch diameter. They can be removed and washed by hose.

The bacterial filters, $53^1/_2$ acres in area and 6 ft. deep, are constructed as water-tight concrete tanks. Coal is used as the filtering medium and has proved a valuable asset in case of national emergency. The best results are obtained from coal ranging from $^3/_4$ to $1^1/_4$ in. in size. The filters are dosed by rectangular distributors 64 ft. long, each with a travel of 249 ft. which discharge only while moving in one direction, thereby providing a rest period between applications of from 12 to 15 minutes. The usual distribution to the filters, is at the rate of 127 gallons per sq. yd. per day, through nozzles of $^{13}/_{16}$-inch diameter which impinge on porcelain plates about 5 inches above the filter surface. The beds are generally in good condition, there is a complete absence of odors, and flies can be kept in check by slight variations in the acidity of the influent.

The filter effluent is of the following general analysis:

	P. p. m.
Oxygen absorbed (4 hr. 80° F.)	32
Alkalinity (to methyl orange)	25
pH	6.0
Nitrogen as free ammonia	20
Nitrogen as albuminoid ammonia	5
Nitrates	3
Suspended solids	104

Catchment Ponds and Clarification Lake.—The filter effluent is further equalized, purified and brightened by passage through 4 ponds with a combined capacity of $4^1/_2$ m. g. and a lake of $10^1/_2$ m. g. with depths of 5

and 4 ft., respectively. The settled humus is returned by pumps to the mixing tanks and precipitation tanks.

The waters in these tanks abound in crustacea, contain a reasonable amount of dissolved oxygen and will support fish life. The effluents are uniformly good, have a slight yellow tinge and are discharged to the river Aire.

Sludge Disposal Works.—The main building of the sludge disposal works contains a grease house, press house, engine house, boiler house and water tower. The grease house contains six 7-ton capacity steel vats for sludge boiling and sixteen similar vats for grease boiling. The hot liquors from the sludge presses are conveyed to the basement where the grease and water are separated by natural means and the grease then further purified. The water is returned to the mixing and precipitation tanks. The hot sludge from the sludge boiling vats flows to six 7-ton displacement vessels from which it is forced by air to the sludge presses in the press house. Each of the 128 presses is operated by compressed air, weighs 15 tons, contains 46 plates 3 × 3 ft. in area and has a capacity of 3200 lb. of 1½-inch cake containing 26 per cent moisture. A basement is provided for automatic loading of sludge cake into cars as the presses are opened. The cycle of operation of the sludge press requires 48 hours. The pressure applied during the first 24 hours is 10 lb., which is then increased to 60 lb. About 48 per cent of the removable grease laden water is extracted in the first seven hours.

The hot sludge cake from the presses is hauled in cars and dumped in heaps 15 ft. high. It is removed from these heaps as required to a disintegrator in which it is powdered and then delivered to railway cars. The total output is disposed of, sales averaging £4000 per annum. The discussion of the paper indicated that at present the market for the recovered grease was not good. J. K. HOSKINS

Coatbridge Sewage Purification and Sludge Disposal Works

ANON.

The Surveyor, **83**, 617–20 (June 16, 1933)

The new sewage disposal plant (simplex surface aeration) for the burgh of Coatbridge, Scotland, is designed to treat completely the dry weather flow of 4.5 m. g. d. The plant was officially opened on May 25, 1933, at which time all parts of the works were in routine operation.

Pre-treatment.—The raw sewage reaches the works through a 36-in. diameter steel pipe supported on a reinforced concrete structure. The

sewage passes first through an inclined bar screen which is hand cleaned and then through a grit tank 12 ft. wide at the top, tapering to 6 ft. at the bottom, which is cleaned by an electrically operated grab dredge. A fine bar screen, mechanically cleaned, is placed at the outlet end of the grit chamber. Presedimentation is provided by six tanks 40 ft. deep in the bottom of each of which are four inverted pyramids each 22 ft. square. Each tank is fed by a 12-inch cast iron pipe from which 9-inch branches discharge to concrete deflector boxes over the center of each inverted pyramid. A sludge well in the center of each tank is connected to the pyramids by 4-inch pipes with valves through which the sludge is drawn by hydrostatic pressure. The effluent from the tanks passes over a series of weirs to the main effluent channel and thence through a regulating chamber designed to control the flow to the aeration units.

Simplex Aeration Tanks.—The design of these tanks is irregular, necessitated by the topography of the site. Two main groups of tanks are provided with a combined capacity of 16 hours dry weather flow and have a total of 50 aerating cones. Each tank is 23.5 ft. deep with a bottom in the shape of an inverted truncated pyramid 22 ft. square at the base. An uptake tube 3 ft. in diameter is placed over each pocket and surmounted by a Simplex cone element. The cones are driven by line shafts and bevel gears from a main shaft, operated by a 75-hp. motor.

Final Settling Tanks.—Primary and secondary settling tanks with a combined capacity of 6 hours dry weather flow receive the effluent from the aeration units. The 8 primary tanks are 22 ft. square and 29 ft. deep, and the 16 secondary tanks are of the same dimensions. Special provision is made for return of sludge from the primary tanks to the aeration units or to the surplus sludge well. The effluent from the secondary tanks is discharged to the steam. The surplus sludge gravitates to a central well and is then pumped to the inlet end of the presedimentation tanks where it settles with the crude sludge.

Sludge Disposal.—Sludge from the presedimentation tanks is drawn to four sludge storage tanks each holding 50 tons and fitted with plate drainers through which the supernatant water is withdrawn and pumped back to the presedimentation tanks. The settled sludge is distributed to three primary digestion tanks each with a capacity of 900 tons. The tanks are provided with double walls with an air cavity between for heat insulation, have floating roofs for gas collection, Dorr stirring mechanism and hot water heating coils. Two secondary digestion tanks which receive the sludge from the primary tanks are open to the atmosphere and are provided with Dorr scrapers. These tanks also act as balancing tanks between the primary tanks and the drying beds. The twelve sludge beds cover $2^{3}/_{4}$ acres and are underdrained. The drainage liquor is returned to the presedimentation tanks.

J. K. HOSKINS

Purification of Trade Wastes (Halifax, England)

ANON

The Surveyor, **83**, 601–2 (June, 1933)

Profound changes in the composition and volume of sewage of Halifax have made necessary revision and enlargement of the purification works. Reduced prices in recent years of by-products from industrial wastes such as wool-scouring and the textile trades have caused the manufacturers to discharge their untreated effluents in increasing volumes to the sewer system. About 40 per cent of the sewage flow consists of such wastes, including wool and piece scours, brewery waste, gas-works liquor, dye wastes, tannery wastes, wire works wastes, etc. In addition to this increase, the entire town, with a population of over 98,000, is being converted to the water carriage system so that at present the dry weather sewage flow is 5 m. g. d.

Salterhebble Sewage Works.—Upon reaching the plant the sewage passes through two flat-bottomed grit tanks and then into two larger hopper bottomed tanks where coarse organic solids are deposited. These tanks are cleaned with fixed dredgers. The sewage next flows through bar screens with 1-inch spaces, after which sulphuric acid is added on the way to the 8 precipitation tanks with a total capacity of 8 m. g. d. The effluent from these tanks is conveyed to the Copley Works for final oxidation.

Sludge Disposal Plant.—These works consist of 2 sludge tanks, 14 sixty-plate filter presses, one continuous band drier and a three-unit solvent grease-extraction plant. Additional acid is added in the sludge tanks to crack the soaps and condition the sludge, the optimum point for separation of water being at pH 3.6. The presses each have 60 plates 3 ft. square and are opened and closed mechanically. Sludge is forced into them at a pressure of 100 lb. per sq. in. through the rams placed in a well below the press house floor. The drier is of the chamber type with traveling endless belts of wire panels which carry the broken press cake. The hot gases in the chamber are kept in motion by 4 fans, each 4 ft. in diameter. The three units of the grease extraction plant each consists of a 5-ton feed hopper, a 5-ton steel shell extractor and three-flow tubular condenser and gravity separator. Benzine is used as the grease solvent, 2400 gallons for each extractor. The recovered grease is blown into lead-lined steam-heated refining vats where, after sulphuric acid is added, it is kept hot for 24 hours before being placed in barrels.

Copley Filtration Works.—The effluent from the Salterhebble precipitation tanks is first screened on reaching the Copley percolating filters. The 36 older filters are arranged in 4 batteries of 10, 6, 12 and 8 units, each varying from 85 to 90 ft. in diameter, 7 to 8 ft. in depth and having a total capacity of 61,600 cu. yd. Ten new filters have been built

from obsolete contact beds, each 6 ft. deep, 135 ft. to 68 ft. in diameter and with a total capacity of 83,100 cu. yd. The filter effluent passes through three humus tanks of 750,000 gallons total capacity.

Activated-Sludge Plant.—To handle the excess day flow of sewage, an activated-sludge plant of the Simplex type has been provided having three aeration pockets with a total capacity of 200,000 gallons and four settling pockets of 55,000 gallons capacity. This plant is operated only during the day and handles an average of 18,500 gallons per hour corresponding to a theoretical detention period of 10.7 hours. Its successful operation is ascribed to the slightly acid nature of the sewage liquor treated. Construction of additional units of the activated-sludge plant is in progress.

J. K. HOSKINS

Human Sewage Effluents Harmless to Cattle

ANON

The Surveyor, **84**, 4 (July 7, 1933)

A case of general interest concerning the effect of sewage plant effluents on cattle was recently decided by the British Court of Appeals in which two land owners brought suit against a municipality that discharged treated sewage into a stream, alleging that cattle had been damaged by drinking the sewage-polluted water which flowed past their farm lands. The lower court had decided the case in favor of the plaintiffs, had awarded damages and issued an injunction restraining the council from discharging noxious effluents into the stream. An appeal was made from this decision by the defendant municipality, the case on rehearing occupying 17 days and being conducted throughout as a claim for actual damages to the plaintiffs' cattle by the defendant's sewage.

The plaintiffs were not able to prove to the satisfaction of the court that the drinking of treated sewage was injurious to cattle and that the poor condition of the cattle was due to the sewage effluent. No evidence in veterinary literature could be cited that claimed harmful effects on cattle resulting from drinking from streams receiving the effluents from sewage treatment works. Moreover, the Royal Veterinary College had maintained three healthy cows for over a year, which had, as their only drink, the effluent from the municipality's sewage treatment plant. Testimony of a number of highly qualified veterinarians was to the effect that human sewage would not harm cattle. The claim that Johne's disease was contracted by the cattle from the diluted sewage in the stream was refuted by the statement that the disease germs might have reached the watercourse through surface drainage of farm lands in an area in which Johne's disease was prevalent.

Based on these arguments, the decision of the lower court was reversed, the judgment for damages was set aside and the injunction was discharged.

J. K. HOSKINS

Dewatering of Sludge

BY A DRAINAGE ENGINEER

The Surveyor, **83**, 525–6 (May 19, 1933)

Mr. James Neave, borough surveyor of Aldershot (England), has had in operation an experimental sludge filter of the covered type, the filtering material of which is heated by steam pipes. The filter is underdrained and consists of 8 inches of coarse clinker, 8 inches of $1^1/_4$-inch gravel and 3 inches of $^1/_8$-inch to $^3/_4$-inch clinker. The heating pipes are $^3/_4$ inch in diameter and carried through the $1^1/_4$-inch size gravel at about 7 inches below the filter surface. Operating data are presented in tabular form showing the temperatures and water content of sludge after various periods. From these figures it appears that the filter with an area of 190 sq. yd. reduced 50 cu. yd. of wet sludge in ten days from 94 to 67 per cent moisture. The author estimates that such a filter might be made to serve a population of 30 persons per square yard of area. The process has been patented.

J. K. HOSKINS

Sewage Treatment at Burnley

ANON.

The Surveyor, **83**, 521–3 (May 19, 1933)

The Borough of Burnley (Great Britain), with a population of 100,000, has recently completed the reconstruction of two of its three sewage treatment plants. The revised scheme as approved by the Ministry of Health, provides for the treatment of the sewage from a population of 85,000, and includes the remodeling of the Duckpits works and a new Simplex type activated-sludge plant, sludge digestion plant and drying beds at the Wood End Works, which latter would handle 2 m. g. d. of dry weather flow, the remaining $^3/_4$ m. g. d. to be treated on existing contact filter beds. An experimental sludge digestion plant has indicated that, when the full sized units are installed, sufficient gas can be produced to supply all the power required at the Duckpits and Wood End works. Until the sludge digestion plant is built, power is being generated by two 100-kw. sets with gas obtained from the local gas department.

Duckpits Works.—This plant is designed to treat a dry weather flow of $2^3/_4$ m. g. d. and three times that volume of storm flow. The

sewage from the inlet channel flows into any one of three screening chambers each 8 ft. wide and 6 ft. deep. Each chamber has coarse bars with 4-inch spaces followed by finer bar screens with bars $^1/_2$ inch apart and which are mechanically cleaned. The screenings amount on the average to $8^1/_2$ tons per week. After passing through the screens the sewage flows through one of three detritus tanks, each 6 ft. wide, 35 ft. long and with a water depth of from 6 to 8 ft. Grit is removed by a traveling telescopic bucket dredger. From 20 to 40 tons of detritus are recovered weekly.

The sewage then passes from one of three separating chambers past a flume recorder along a 4-ft. channel to seven sedimentation tanks with a present capacity of 1,884,000 gallons ($16^1/_2$ hr. d. w. f.). These old tanks have been improved by provisions for better distribution of the incoming flow, decanting of the supernatant liquor and removal of the settled sludge. Existing storm water tanks have been altered to provide a total capacity of 1,075,000 gallons or $9^1/_2$ hrs. d. w. f.

Wood End Works.—The aeration plant has a capacity of 2 m. g. d. and consists of five units each consisting of 8 aeration tanks in series, one primary and two secondary settling tanks. Each aeration tank is 25 ft. square with a water depth of 12 ft., while the pockets are $5^3/_4$ ft. deep and 13 ft. square at the bottom, with a resulting capacity of 36,400 gallons. The five primary settling tanks are each 25 ft. square for the first 2 ft., then tapering in the next 20 ft. to 2 ft. square at the bottom, each with a capacity of 36,850 gallons or $2^1/_4$ hours' detention of the dry weather flow. The two secondary settling tanks in each unit are of approximately similar size with 33,250 gallons capacity or, for all ten tanks, a detention period of four hours d. w. f.

J. K. HOSKINS

Death of Fish from Cyanides in Coke-Oven Effluents

BY C. H. S. TUPHOLME

Ind. Eng. Chem., News Ed., **11**, 211 (July, 1933)

Investigations carried out by the Water Pollution Research Board on pollution of the water of the river Tees estuary indicate that cyanide is responsible for the death of salmon and sea trout smolts. The dissolved oxygen content of samples of water collected throughout the length of the estuary, where fish were dying, varied between 40 and 70 per cent of saturation. Forty-nine per cent of these samples were toxic to trout. When the cyanide was removed from the toxic samples by the addition of formaldehyde, 94 per cent were rendered non-toxic. Experiments showed that trout are rendered helpless in less than one hour in a solution containing 0.14 p. p. m. of potassium cyanide at 5° C.

The effluents from the gas coolers of coke oven plants discharged approximately 800 kg. per day of cyanide into the estuary during the period under investigation. A substantial reduction in the cyanide content of the effluent occurred when the liquor was sprayed at 58° C., the toxicity to trout being reduced to about one-sixteenth of its original value.

P. D. MCNAMEE

Heating Top Sludge, II

BY HENRY W. TAYLOR

Public Works, 64, No. 7 (July, 1933)

The preceding article of the series described experiments conducted at Saranac Lake, N. Y., in heating top sludge by circulating hot air into the attic space between the weather roof and ceiling plate of the floating cover.

The present article describes the results during May at Saranac Lake and the experiments in heating top sludge conducted at Rome, N. Y. With only a slight drop in the average temperature of the tank contents, a variation of about 15° F. (abstracter's estimate from graph) in the top sludge produced a change in gas yield from 8900 cu. ft. to 6400 cu. ft. at Saranac Lake. Similarly, at Rome, the preceding 5 months' average yield was 10,700 cu. ft. with an average top sludge temperature of 61° and an average tank temperature of 80° as against the May figures of 14,005 cu. ft. with an average top sludge temperature of 83° and an average tank temperature of 81° F. The average yearly gas yield at Saranac Lake was 0.64 cu. ft. per capita per day, and at Rome 0.54 cu. ft. The effects of other variables are considered by the author to be negligible. It is planned to reverse the effect and use the blowers during the summer to control foaming and undue digestive activity. The author points out that the control of gas production becomes more necessary as utilization of sludge gas increases.

R. W. KEHR

Pre-aeration of Sewage by Air Diffusion

BY FRANK C. ROE

Public Works, 64, No. 7 (July, 1933)

The presence of oil and grease is detrimental to sludge digestion and secondary treatment, and gives visual evidence of the presence of sewage when disposal is by dilution. Oil and grease may be removed by diffused air aeration where the emulsified particles are carried to the surface by air bubbles and form a scum which can be handled through a scum trough at the outlet end where there is no agitation, or by scum removal devices on

settling tanks. Quantities removed by such units average as high as 7 cu. ft. per million gallons of sewage. At Dodge City, Kansas, four 24-hour composites showed from 44 to 63 per cent fat removal between raw and settled sewage with 13 minutes' pre-aeration. Other results of pre-aeration at Dodge City are odor removal and assistance to sedimentation. Pre-aeration periods vary from 10 to 30 minutes, use from $^1/_{10}$ to $^1/_{20}$ or less cu. ft. of air per gallon and, with a modified ridge-and-furrow tank design, require 20 to 30 sq. ft. of diffuser plates per m. g. d. capacity. A drawing of the Whittier, Cal., unit, 10 ft. wide × 40 ft. × 9 ft. deep, for 1.8 m. g. d., is shown. This unit has a 10 ft. × 10 ft. section on the outlet end with scum trough and bottom outlet pipe. R. W. KEHR

Operation of a Small Sewage Treatment Plant

BY FLOYD G. BROWNE

Public Works, **64**, No. 7 (July, 1933)

The recently completed plant at Delphos, Ohio, is designed to treat 0.6 m. g. d. from a population of 6000. The dry weather flow is intercepted and taken to the plant in a 48-in. line. Equipment consists of a hand raked bar screen, two grit chambers, mechanical clarifier, gas collecting digester, chlorinator, 3 glass-covered sludge beds. The pumping and chlorinating equipment, office and laboratories are housed in a brick building. One operator cares for the plant. His duties include: emergency night duty, inspection, cleaning, maintenance, operation, sampling at definite intervals and simple routine tests. Part time technical supervision is provided in accordance with State Board of Health regulations. Inspections are made about twice a month.

An average of 5.2 cu. ft. of screenings per m. g. from the $1^1/_2$-in. screens were buried. The grit chambers were used during the first flush of a storm and removed 9.7 cu. yd. during the year. The clarifier removed 86 per cent suspended solids and 59 per cent B. O. D. (daytime flow composites) with $2^1/_2$ hours' actual detention. Sludge removed averaged 7.1 per cent solids pumping 10–15 min. daily.

Sludge storage design capacity is 2.5 cu. ft. per capita and drying bed area 0.57 sq. ft. per capita. The digester was placed in operation by filling with raw sewage, bringing this to working temperature (70–80° F.) and stirring continuously. About 400 gallons of sludge were then pumped daily. No trouble was experienced with foaming or suspended solids in overflow. Volatile matter is reduced from 60 to 39 per cent, and moisture content from 93 to 84 per cent. R. W. KEHR

Some Causes and Effects of Stream Pollution

BY J. K. HOSKINS

Public Works, **64**, 11–12 (August, 1933)

In general, polluting substances discharged to streams may be classified as: (1) toxic or harmful stable chemicals, such as poisons, acids, alkalies, oils, dyes and similar substances; (2) inert substances such as clay, sawdust, wood pulp and carbon; and (3) organic matter, including sewage and numerous industrial wastes.

The first class are most varied in composition and frequently very difficult to remove if they reach streams. This class exerts a direct detrimental effect upon animal and plant life. The unfavorable effects generally manifested are classified by Donaldson as: (*a*) disagreeable odors and tastes; (*b*) unsightly appearance or interference with treatment processes; and (*c*) damage to water works structures, and rendering the water less fit for domestic and industrial use. The most common and abundant substance falling under the second class is soil washed in by surface run-off.

The third class, including sewage and industrial wastes, decompose in the receiving stream, reduce the dissolved oxygen content and frequently contain pathogenic organisms.

Self-Purification.—Harmful effects of chemicals are generally greatly reduced or eliminated by dilution, and frequently by chemical reactions between each other or with mineral matter carried in suspension or solution in the stream. Inert substances generally settle out.

The natural purification of organic polluting material in streams is dependent upon the biochemical action of bacteria and plankton present in the water. A wide variety of bacteria in water use the organic matter for food, breaking down the complex compounds in the process and converting them into stable forms when an excess of dissolved oxygen is present.

Extended observations indicate that these bacteria are most active during the time of their multiplication. When no agencies are present to interfere with their normal reproduction, multiplication of bacterial numbers will proceed to a definite maximum depending upon the available food supply—that is, organic pollution. During this multiplication stage, available dissolved oxygen is used up, but when the upper limit of bacterial concentration is reached, further activity practically ceases and little further oxygen is required. If some natural enemy is introduced that reduces the bacterial concentration, such as bacteria-eating plankton, further multiplication is stimulated to maintain the upper limiting number, and oxidation of the organic matter again proceeds to completion. One of the functions of the animal plankton in polluted water is to maintain a

biological balance and stimulate the development of bacterial cells which in turn is necessary for the natural course of oxidation of organic matter.

These bacteria and plankton are normally present in polluted water, but the supply of dissolved oxygen required for their oxidation work is the factor that usually limits the speed of natural purification in polluted streams. When this oxygen supply is deficient, objectionable putrefactive conditions result.

Nature provides the replenishment of dissolved oxygen by re-aeration under well defined laws. Natural purification of streams may be encouraged by artificial means as follows: the precipitation of suspended matter through storage facilities of reservoirs; hastening re-aeration by extensive surface exposure; agitation or turbulence of the flowing water; adding oxygen-bearing chemicals to furnish an additional source of available oxygen; and by temporarily delaying biochemical oxidation by the addition of disinfecting chemicals such as chlorine. C. T. WRIGHT

The Removal of Cyanide from Plating Room Wastes

BY E. F. ELDRIDGE

Michigan Engineering Experiment Station Bulletin, No. 52 (1933)

Plating Room Methods.—In general, the parts to be plated are suspended in a plating solution containing potassium or sodium cyanide. The cyanide solution is then rinsed from the parts, this being the chief source of cyanide found in the waste water. Another source is from the drippings which fall from the parts being transferred from the plating to the washing vats. Results of analysis indicate that the average plating room wastes contain between 100 and 300 p. p. m. of potassium cyanide.

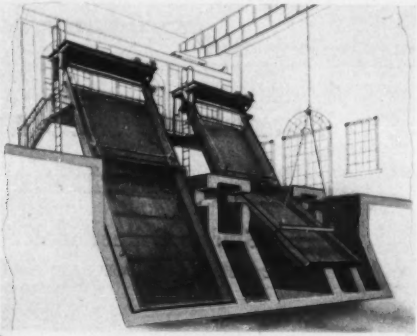
Present Methods of Waste Disposal.—For the disposal of cyanide wastes, there are two methods in general use, (1) dilution and (2) ponding. Dilution by discharge into streams should only be practiced when the volume of the stream water is sufficient to reduce the cyanide content below the fatal dose for aquatic life. Ponding is effective in reducing the cyanide content of the waste but there is danger of seepage into water supplies.

Experimental.—Treatment with chlorine was of little value in reducing the toxicity of the waste, as the cyanogen chloride produced had about the same toxicity as the cyanide. The toxicity threshold for different types of fish varied from 0.25 to 1.0 p. p. m. Precipitation with ferrous and ferric salts failed to reduce the cyanide content below 50 p. p. m. A solution of potassium cyanide was mixed for thirty minutes with the theoretical amount of potassium permanganate necessary to oxidize it to cyanate.

On standing overnight, the sludge settled out leaving a clear supernatant liquor. This treatment produced a satisfactory effluent although still somewhat toxic to fish when undiluted. When diluted one to one, fish lived in it as well as in the controls. It was concluded that either a small amount of potassium cyanide remains in the solution or that the toxicity threshold of the cyanate is between 125 and 150 p. p. m. A satisfactory effluent can also be obtained by acidifying and aerating the sludge. This treatment applied to a solution containing 500 p. p. m. of potassium cyanide, treated with 10 per cent more than the calculated amount of acid, completely removed the cyanide in sixteen hours, about 90 per cent being eliminated in the first six hours. The cost of treating 10,000 gallons of waste with permanganate is $2.15 against $2.04 for the acid treatment. Conclusion was that there is very little choice of one method over the other. Cyanide wastes inhibited sludge digestion, the length of the inhibiting effect depending on the cyanide content. P. D. MCNAMEE

LINK-BELT STRAIGHTLINE Equipment

. . . For Positive Results and High Efficiency



The Old Way

Actual photograph of the hand cleaning operation at the Baltimore plant before the installation of Link-Belt Straightline mechanically cleaned bar screens.

GOOD appearance and utility were combined in the design of this new screening installation at Baltimore's Back River Disposal plant. The two STRAIGHTLINE mechanically cleaned screens illustrated have replaced the old-fashioned hand method of doing this unpleasant job.

These dependable units assure constant, automatic removal of screenings, which are discharged direct into a shredder, macerated and returned to the sewage. The shredder chute and dead plate are washed with water jets which are automatically turned on after each discharge. By means of a gantry crane, the screening rack can be swung clear of the sewage for inspection.

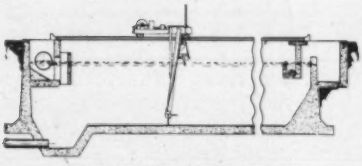
Credit is due the engineers of the Sewerage Dept. for the skill and care shown in the design of this plant. George E. Finck is chief, and C. E. Keefer is in charge of design. Send for Book No. 642.

LINK-BELT COMPANY

PHILADELPHIA, 2045 West Hunting Park Avenue CHICAGO, 300 West Pershing Road
SAN FRANCISCO, 400 Paul Ave. TORONTO, Eastern Ave. & Leslie St. Offices in Principal Cities

LINK-BELT 4804-A

SCREENS • COLLECTORS • AERATORS • GRIT CHAMBERS • DISTRIBUTORS



Hardinge Rectangular Clarifier

for Sludge Collection & Skimming in Rectangular Sewage Settling Tanks

The Hardinge Rectangular Clarifier consists of a traveling crane automatically operated and equipped with a sludge scraper that moves settled solids to the sludge discharge hoppers and a skimmer that collects all floating material in a scum trough.

Made in single units with individual drive or multiple units with single drive.

Can be installed in existing settling tanks with minor changes.

Write for Bulletin 38 describing this and other Hardinge sewage plant equipment.

Hardinge Company, *Inc.*
York, Pa.

122 E. 42nd Street
NEW YORK

205 W. Wacker Drive
CHICAGO, ILLINOIS

Hardinge-Western Co., SAN FRANCISCO, CALIF.

Hardinge

:: DIRECTORY OF ENGINEERS ::

George W. Fuller — James R. McClintock
F. G. Cunningham — Elmer G. Manahan
C. A. Emerson, Jr. — W. Donaldson
E. W. Whitlock

FULLER & McCLINTOCK
Engineers
New York, 170 Broadway

Water Supply, Water Purification, Sewerage, Sewage Disposal, Garbage and Industrial Wastes Problems, Valuation and Rate Regulation of Public Utilities.

NICHOLAS S. HILL, JR.
Consulting Engineer

Specializing in Sewerage and Sewage Disposal, Water Supply and Water Purification, Valuations and Reports.

Chemical and Biological Laboratories.

112 East 19th Street **New York, N. Y.**

PEARSE, GREELEY & HANSEN
Hydraulic and Sanitary Engineers

Investigations and Reports. Plans and Specifications. Supervision over Construction. Supervision over Operation.

Water Supply and Purification
Sewerage and Sewage Disposal
Garbage Collection and Disposal
Valuation and Appraisals

6 North Michigan Avenue, Chicago, Illinois

MORRIS KNOWLES, Inc.
Engineers

Water Supply and Purification, Sewerage and Sewage Disposal, Valuations, Laboratory, City Planning.

Pittsburgh, Pa.

BLACK & VEATCH
Consulting Engineers

Sewage, Sewage Disposal, Water Supply, Water Purification, Electric Lighting Power Plants, Valuations, Special Investigations, Laboratory Service and Reports

307 S. Hill St., Los Angeles, Cal. **230 Park Ave., New York City**
Mutual Building, Kansas City, Mo.

METCALF & EDDY
Engineers

Harrison P. Eddy — John P. Wentworth
Charles W. Sherman — Harrison P. Eddy, Jr.
Almon L. Fales — Arthur L. Shaw
Frank A. Marston — E. Sherman Chase

Water, Sewage, Drainage, Municipal Refuse and Industrial Wastes
Valuations Laboratory

Boston **Statler Building**

ALBRIGHT & FRIEL, INC.
Engineers

Chester B. Albright — Francis S. Friel

Water Supply and Purification
Sewerage and Sewage Disposal
Industrial Waste and Refuse Disposal
Investigations Valuations Reports

246 South Fifteenth Street
Philadelphia, Penna.

John W. Alvord
Charles B. Burdick
Louis R. Howson
Donald H. Maxwell

ALVORD, BURDICK & HOWSON
Engineers

Water Works, Water Purification, Flood Relief, Sewerage, Sewage Disposal, Drainage, Appraisals, Power Generation

Civic Opera Building **Chicago**

GEORGE B. GASCOIGNE
Consulting Sanitary Engineer

W. L. Havens — A. A. Burger
F. W. Jones — F. C. Tolles

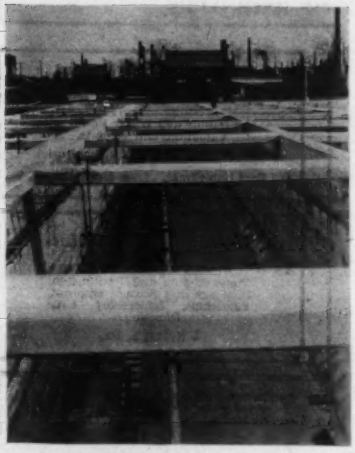
Sewerage and Sewage Disposal, Water Supply and Purification, Treatment of Industrial Wastes.

Cleveland **Leader Building**

Are you interested in a popular periodical giving you the latest information on the subjects of Chemistry, Physics and Biology? It is interesting and contains many illustrations. Write for a free sample copy and descriptive folder.

THE SCIENCE LEAFLET

654 Madison Avenue **New York, N. Y.**



Plans and specifications by H. P. Jones and Co. of Toledo. Construction by Green & Sawyer Co. of Lima.

In Another Modern Sewage Disposal Plant . . .

NORTON Porous Plates—proven by years of use in cities all over the country—were selected for Lima's activated sludge sewage treatment plant . . . . a part of this Ohio city's sanitary improvement program.

Strength and uniformity are the important factors in porous plates used for the aeration of sewage. And both are provided in Norton Porous Plates . . . . for back of them are years of experience in manufacture and in applying porous mediums to sewage treatment processes.

NORTON POROUS TUBES AND PLATES

NORTON COMPANY
Worcester, Mass.
New York Chicago Cleveland

R-465

NORTON PRODUCTS Grinding Machines; Lapping Machines ◆ Grinding Wheels; Abrasives for Polishing; India Oilstones, Pulpstones ◆ Laboratory Ware, Refractories; Porous Plates ◆ Non-slip Tiles and Aggregates

PARDEE

CHLORINATORS

PARDEE ENGINEERING COMPANY
3915 29TH STREET
LONG ISLAND CITY, N. Y.

CHEMISTRY IN AGRICULTURE

Edited by
Joseph S. Chamberlain and C. A. Browne

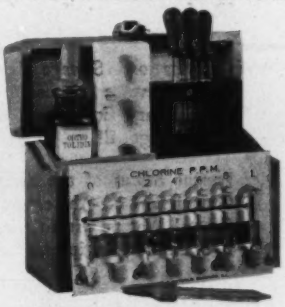
This is a cooperative work intended to give examples of the contributions made to agriculture by chemistry.

Each of the sixteen chapters is written by a recognized authority in his own field.

This book is distributed at the cost price of $1.00 per copy for educational purposes.

THE
CHEMICAL FOUNDATION, INC.
654 Madison Avenue,
New York, N. Y.

The S. D. C. Residual Chlorine Tester



Cat. No.
200 S. D. C. Residual Chlorine Tester, complete in a wooden cabinet, as described and illustrated, with directions. Each.....$12.00

Write for descriptive circular. This set has been accepted by many nationally known laboratories and is the most rapid residual chlorine tester available.

RASCHER & BETZOLD
829 Orleans Street Chicago, Illinois

To Appear Shortly in the

American Journal of Public Health

Recent Advances in the Chemical Treatment of Sewage. F. W. Mohlman, Director of Laboratories, Sanitary District of Chicago, Chicago, Ill.

Sewage Sludge Gas Utilization. C. E. Keefer, Bureau of Sewers, Department of Public Works, Baltimore, Md.

Mechanization of Sewage Treatment Works. E. B. Besselievre, Sanitary Engineer, The Dorr Company, New York, N. Y.

The Treatment of Trade Wastes. L. F. Warrick, State Engineer, State Board of Health, Madison, Wis.

Chlorination in Sewage Disposal (Report of the Committee on Sewage Disposal). Chairman, Langdon Pearse, Sanitary Engineer, Sanitary District of Chicago, Chicago, Ill.

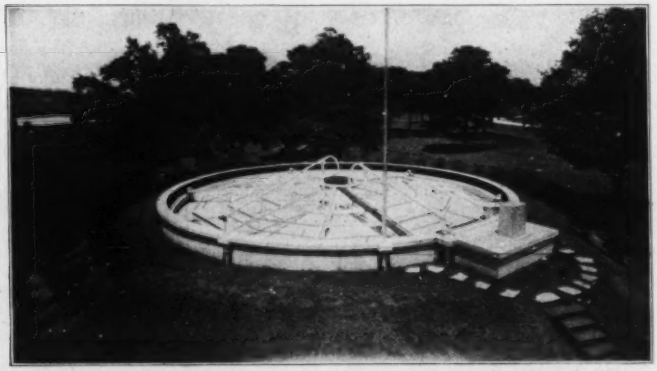
Present Status of the Program of the Tri-State Treaty Commission on Abatement of Pollution of Harbor and Coastal Waters within the (N. Y.) Metropolitan Area. F. S. Tainter, Engineer, New York, N. Y.

Subscription $5.00 per year

AMERICAN PUBLIC HEALTH ASSOCIATION

450 Seventh Avenue, New York, N. Y.

PFT FLOATING COVER
ADDITION TO
ELGIN, ILL., SANITARY DISTRICT TREATMENT PLANT



In providing additions to the existing Imhoff tank installation the PFT Floating Cover was selected as the best means for obtaining flexibility of operation in the separate sludge digestion unit.

The digestor is 50 feet in diameter and since it was placed in operation in the Fall of 1932 by E. E. Smith, District Superintendent, gas production has been continuous and at expected rates.

Roofing has not been placed on the cover, and notwithstanding this fact, heat losses have been negligible even during prolonged low temperature periods of the past winter.

PACIFIC FLUSH TANK COMPANY

Designers & Manufacturers of Sewerage and Sewage Treatment Equipment

4241 RAVENSWOOD AVE. CHICAGO, ILL.

EXCLUSIVELY SINCE 1893

136 LIBERTY STREET NEW YORK, N.Y.

INDEX TO ADVERTISERS

	Page
Albright & Friel, Inc.	9
Alvord, Burdick & Howson	9
American Public Health Association	12
Black & Veatch	9
Carborundum Company, The	5
Cast Iron Pipe Research Assn.	2
Chain Belt Company	3
Chicago Pump Company	6
Dorr Company, The	4
Fuller & McClintock	9
Gascoigne, George B.	9
Hardinge Company, Inc.	8
Hill, Nicholas S., Jr.	9
Knowles, Inc., Morris	9
Link-Belt Company	7
Metcalf & Eddy	9
Norton Company	10
Pacific Flush-Tank Company	13
Pardee Engineering Company	11
Pearse, Greeley and Hansen	9
Rascher & Betzold	11
Wallace & Tiernan Company, Inc.	Back cover

When writing these, please mention the

SEWAGE WORKS JOURNAL